EFFECTS OF INTERCROPPING ARRANGEMENTS AND FERTILIZER APPLICATION ON GROWTH AND YIELD OF AFRICAN NIGHTSHADE (*Solanumnigrum*L.) IN KISII COUNTY, KENYA

NYAGARI ONYARI ERICK

BSc. Horticulture (Hons)

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN HORTICULTURE

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

2016

DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other University.

Nyagari Onyari Erick Signature………………………Date…………………

This thesis is submitted with our approval as University supervisors

Dr. Cecilia Moraa Onyango Signature…………………..... Date………................

Department of Plant Science and Crop Protection

University of Nairobi

Dr. Richard Ndemo Onwong'a Signature…………………… Date…………….......

Department of Land Resource Management and Agricultural Technology

University of Nairobi

DEDICATION

This thesis is dedicated to my dear father Mr. James Nyagari, mom Mrs. Catherine Nyagari and my family members for their continued support during my study, thank you!

ACKNOWLEDGEMENTS

I thank the Almighty God for His sufficient grace and favor that saw me complete my studies.

I am really grateful to my supervisors Dr. Cecilia Moraa Onyango and Dr. Richard Ndemo Onwong'a for their tireless commitment, insightful guidance and support during the entire period of study.

My sincere gratitude goes to the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for awarding me a post graduate scholarship and funding this study.

I am also grateful to the teaching and support staff of the Faculty of Agriculture, Department of Plant Science and Crop Protection for their assistance towards my work.

I thank the Ministry of Agriculture, Livestock and Fisheries' staff in Kisii for their assistance during my field work.

My gratitude goes to everyone else who offered assistance and direction towards the successful completion of my study, I may not mention each one of you but I am really grateful. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

GENERAL ABSTRACT

The study evaluated effects of intercropping arrangements and fertilizer combinations on growth and yields of *Solanum nigrum* L., soil nutrient balances and gross margins. The study was carried out at Kenya Agricultural and Livestock Research Organization (KALRO) in Kisii County for two seasons in the short rains 2015 and long rains 2016. The experiments were laid out in a randomized complete block design with a split plot arrangement replicated thrice. The main plots were intercropping arrangements of spider plant: African nightshade rows (intercrop ratios of 0:16, 1:14, 1:2, 1:3, and 1:4) and sub plots were fertilizer combinations of Farm Yard Manure (FYM), urea (NPK: 46-0-0) and triple super phosphate (NPK: 0-46-0). Data on number of branches per plant, number of leaves per plant and fresh leaf yield were measured. The total fresh leaf yield was used for gross margin analysis. Nutrient status and balances were determined for pH, Organic carbon, N, P and K analyzed before planting and after harvesting using nutrient monitoring (NUTMON) tool box. The results indicated that fertilizer combinations had a significant (P=0.05) effect on the number of branches and leaves per plant. The application of urea (60kg N ha^{-1}) +TSP (40kg P ha^{-1}) resulted in the highest number of branches and leaves (10 branches and 32 leaves per plant) while application of FYM (60kg N ha^{-1}+ 36 kg P ha^{-1})resulted in the lowest number of branches and leaves (6 branches and 21 leaves per plant). On total fresh leaf yield, sole African nightshade supplied with Urea (60kg N ha^{-1}) + TSP (40Kg P ha^{-1}) resulted in the highest fresh leaf yield (35.1 tons ha^{-1}). This however was not significantly different from sole African nightshade supplied with urea (40 kg N ha^{-1}) + TSP (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) that resulted in 32.5 tons ha^{-}1. An intercrop ratio of 1:2 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest fresh leaf yield (8.9 tons ha^{-1}). The results further showed that intercropping arrangements and fertilizer combinations had a significant (P=0.05) effect on soil nutrient status and balances. In terms of nutrient status, plots containing sole African nightshade and 1:4 intercrop ratio supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) had a soil pH of 6.3 while plots with intercrop ratios of 1:2, 1:4, 1:3 and 1:14 supplied with urea (60 kg N ha^{-1}) + TSP (40 kg P ha^{-1}) had a pH of 5.58. Further an intercrop ratio of 1:14 supplied with FYM (60 kg N ha^{-1}+ 36kg P ha^{-1}) resulted in 0.46% N while an intercrop ratio of 1:2 supplied with urea (40 kg N ha^{-1})+ triple superphosphate (30 kg P ha^{-1})+FYM (20 kg N ha^{-1}+ 9kg P ha^{-1})or urea (60 kg N ha^{-1})+ triple superphosphate (40 kg P ha^{-1}) resulted in 0.3% N and a phosphorus content of 11.7ppm after harvest. Further, plots containing sole African nightshade as well as intercrop ratios of 1:3 1:4, and 1:14 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in 8 $cmolkg^{-1}$K and 3 % C while plots supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) or urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1})resulted in 4 cmol kg $^{-1}$ P across all intercropping arrangements. Further, Sole African nightshade supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded nutrient balances of -9 kg N, -9.9 kg P and -5.4 kg K ha^{-1} yr^{-1} while an intercrop ratio of 1:2 with an application of urea (60 kg N ha^{-1})+ triple superphosphate (40 kg P ha^{-1}) recorded nutrient balances of -36.5 N, -25.2 P and -34.2 kg K ha^{-1} yr^{-1}. On gross margin analysis, African nightshade grown at an intercrop ratio of 1:4 supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) resulted in highest gross margin of KES 294,243 followed by sole African nightshade supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) that resulted in KES 276,091 while an intercrop ratio of 1:2 supplied with FYM(60kg N ha^{-1}+ 36 kg P ha^{-1}) gave the lowest gross margins of KES 37,354.

It can therefore be concluded that intercropping arrangements and fertilizer application influenced growth and yield of African nightshade, nutrient balances and gross margins. Further increase in spider plant population and/ or farm yard manure with the corresponding reduction of inorganic fertilizer resulted in low yields of African nightshade with low nutrient losses compared to when only inorganic fertilizer was used. However, combined yields for both vegetables with high ratios of inorganic fertilizer gave the highest gross margins. Therefore for a profitable vegetable enterprise, farmers should grow African nightshade at an intercrop ratio of 1:4 with nutrients supplied from urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) to maximize on gross margins but for farmers who opt to grow a mono crop of African nightshade then nutrients must be supplied from only inorganic fertilizers. However, for those farmers who cannot afford inorganic fertilizers, can grow African nightshade at an intercrop ratio of 1:2 supplied with FYM (60 kg N ha^{-1}; 36 kg P ha^{-1}) since it is also profitable and facilitates reduction in soil nutrient losses. Although these technologies will empower small scale farmer economically, more has to be done to realize the most compatible vegetable intercrops with African nightshade, that will enhance nutrient use efficiency, reduce production costs and maximize gross margins.

Key words: African nightshade, farm yard manure, nutrient balances, gross margin

CHAPTER ONE

INTRODUCTION

A huge potential is held by Africa's diversity that will transform agricultural systems to contribute to economic rejuvenation hence eradicate poverty (Salami et al. 2010). Kenya faces major challenges of food security with over half of Kenyan population live under poverty line with little access to healthy food (Government of Kenya 2010). This is as a result of prolonged droughts, extreme poverty, poor agronomical practices and high population growth, in which the current population is estimated at 42 million and expected to double by 2050 (Government of Kenya 2011). Severe malnutrition and food insecurity caused by lack of enough food due to soil fertility deterioration and floods has led to less production and over-reliance on some selected crops like maize and millet that have inadequate essential nutrients for human health (Sands et al. 2000). Over-whelming reliance on cereals increases healthy problems that are escalating in most of the developing countries majorly for children (Smith et al. 2000).

African nightshade is vitally an important source of micronutrients, fiber, vitamins and minerals having essential components of a balanced and healthy diet (Kamga et al. 2013). In most of the developing countries, about 43% of these requirements are met which in itself is difficult to comprehend as vegetables are clearly a major potential source of cash income for small-holder farmers and offer a much more effective way for subsistence farmers to grow themselves out of poverty than growing starchy staples alone (Chadha and Mndiga 2007). Over the last few years, African nightshade has made a breakthrough from being cultivated at homes to being commercialized in big towns and served in big hotels (Chivenge et al. 2015). Because of the promotions by NGOs and research and other same minded groups, the trend has drastically changed based on nutritional awareness and benefits accrued to medicinal values that have seen it become cultivated and commercialized vegetable (Abukusta-Onyango et al. 2004).

However, the only way to increase African nightshade production in marginal units of farming is to increase productivity per unit area and time through intercropping and judicious fertilizer application. Intercropping leads to efficient utilization of farm resources, increased production per unit area, brings greater stability from season to season than sole cropping system and aid in controlling pests and diseases. Besides, increased yields, modification of planting arrangement and patterns of the base crop will make intercropping feasible and remunerative to farmers. In regard to increased production, enhanced food production in sub Saharan Africa is dependent on external nutrient inputs, especially Nitrogen, Phosphorous and Potassium of which is facilitated by continuous cultivation with little or no supply of nutrients that leads to negative soil nutrient balances (Cobo et al. 2010). Mineral fertilizer use has been limited because of low availability and lack of purchasing power by small holder farmers (Morris et al. 2007). However, combined use of inorganic fertilizers and farm yard manure is gaining recognition forming an important part of management for soil fertility as key way of addressing soil healthy deterioration with low external input systems (Vanlauwe et al. 2010a). Greater yield benefits can be achieved from combining farm yard manure and inorganic fertilizer; however this depends on various factors such as bio-physico chemical soil environment and intricate interaction effects among intercropping systems (Chivenge et al. 2009; Giller et al. 2001a).

Nevertheless, soil nutrient balances must be calculated to estimate annual loading of nutrients from agricultural soils which gives an indication of potential risk associated with nutrient losses to the environment hence efficient and effective approach to slowing down nutrient losses is required to maintain and/or increase crop productivity and sustainable agriculture in the long run

(Gruhn et al.2000). Use of well modernized soil fertility systems that includes farm yard manure and right quantities of inorganic fertilizers are critical in enhanced and sustainable vegetable production. It provides wide choice for use of low external inputs to small scale farmers but most of the farmers are still staggering on how much of these low external inputs to apply (Kimani *et al.*, 1998). Thus, farm-NUTMON tool will help in assessing the amount of both farm yard and inorganic fertilizer farmers use and mining of soil nutrients through harvested crops, removing crop residue, mineral leaching, and through run offs which will be the basis of how much to supply for sustainable and increased crop production. Against this milieu, the main aim of the study was to contribute towards enhanced African nightshade production in smallholder farming systems through integration of spider plant in African nightshade production combined with use of farm yard manure and inorganic fertilizer application.

1.1 Statement of the problem

Low leaf yields of 1-3 tons ha^{-1} against its potential of 35-40 tons ha^{-1} has led to low supply below consumer demand of the African nightshade (ref..). Soil fertility depletion, particularly of nitrogen, phosphorus and potassium, has been identified as a fundamental root cause of declining crop productivity however the need to replenish these nutrients in food production has thus been recognized for a long time (ref..). This is compounded by the general belief that traditional vegetables are adapted to low fertility has led to low or no usage of fertilizers on these crops coupled with paucity of information on intercropping arrangements and fertilizer applications in the production of African nightshade (Opala et al. 2013).

There is inadequate research and information on the optimal production of African nightshade in terms of intercropping systems and fertilizer applications which calls for the development of an appropriate cropping system and fertilizer use that will unlock the potentiality of the vegetable.

1.2 Justification

African nightshade is often intercropped with other crops and rarely occupies the significant portion of the farm however the intercropping systems and arrangements do not optimize its production. Spider plant is among the indigenous vegetables that are highly nutritious, medicinal value, source of income and it acts as an anti-feedant repellant to pests hence reduce the cost of pesticides and pest severity on African nightshade. Sustainable intercropping arrangements will increase food base and empower smallholder farmers economically with limited resource available. Further the use of combined fertilizer sources (organic and inorganic) will not only increase the yields of African nightshade but also will ameliorate soil properties that will lead to sustainable crop production. This is opposed to the conventional methods of production of using excess fertilizer or not using any fertilizer.

Regardless of yield reduction of the component crops, intercropping of African nightshade with spider plant will facilitate better use of nutrients supplied from inorganic fertilizer and farm yard manure hence reduce nutrient losses. In addition intercropping will increase nutritional diversity and accrued economic benefits.

Generally appropriate cropping system and fertilizer combinations will unlock the potentiality of the crop that will reveal enormous benefits; economically, health, environmental sustainability, food security and conservation of biodiversity.

1.3 General objective

To contribute towards enhanced African nightshade production in smallholder farming systems through spider plant integration in African nightshade production combined with fertilizer applications from 3 tons to about 35 tons.

1.3.1 Specific objectives

1. To evaluate the effect of intercropping arrangements combined with fertilizer applications on growth and yield of African nightshade.

2. To monitor soil status and nutrient balances in different intercropping arrangements and fertilizer combinations

3. To calculate Gross Margin analysis for different intercropping arrangements and fertilizer combinations on the production of African nightshade

1.4 Hypothesis

1. Intercropping arrangements combined with fertilizer applications increase the growth and yield of African night shade.

2. Inter cropping arrangements combined with fertilizer applications change the soil nutrient status and balances.

3. Gross margins are increased by different cropping arrangements and fertilizer applications.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

African nightshade belongs to genus Solanum in solanaceae family that comprises of approximately 90 genera and 3000 species and widely diversified in the tropics (Edmonds and Chweya, 1997). African nightshade is one of the indigenous leafy vegetables cultivated in most of small holder farmers' fields in Kenya (Abukusta-Onyango et al. 2004). African nightshade has been cultivated in Kenya for some years now that it is still regarded as an important crop (Gockowski et al.2003). African nightshade provides increased food base and is the most preferable vegetable in terms of nutrition compared to exotic vegetables in Kenyan Markets. The vegetable is high in calcium, vitamins A and C and iron that are so beneficial to human health (Schippers et al.2002).

The consumption of traditional vegetables is part of cultural custom, with lots of importance in various communities' heritage and helps in empowering women who are depended on in most of the families (Chivenge et al., 2015). The adoption of exotic vegetables in sub Saharan Africa has led to negative impact on cultivation and utilization of traditional vegetables. During colonial periods, a neglecting of the traditional vegetables was done and efforts were made to promote the exotic vegetables. Diversified diet is critical for providing adequate nutritional quality through adoption of a sustainable food-based strategy that points on increasing consumption of leafy vegetables, fruits and legumes in a cost-effective intervention method to control nutrient deficiencies and human disorders (Gockowski et al., 2003). Even if traditional leafy vegetables contribute largely in nutritional improvement, food security, increased income and better livelihoods for small holder farmers, its potential to meet the burgeoning demand for consumption has not been exploited fully due to lack of quality seeds (Onim and Mwaniki, 2008).

2.2 Production status and consumption of African nightshade in Kenya

Contrary to its potential, Africa still struggles with malnutrition problems, of which it is well diversified in terms of indigenous vegetables which are rich in micronutrients (Oniang'o et al. 2005). Consumption of vegetables per capita, in sub-Saharan Africa is still low compared to other regions. It is evident that utilization of traditional vegetables in developed countries increased significantly, while sub-Saharan Africa showed decline of vegetables per capita consumption (Segre et al. 1998). However, it is emerging that African nightshade is much now in prestigious hotels and events (Shiundu and Oniang'o, 2007). Consumers are becoming increasingly aware of the nutritional and medicinal value of this vegetable. This has led to an upsurge in the demand in the demand leading to an estimated production and consumption of about thirty tones in urban areas (Mwangi and Mumbi 2006) however production and consumption estimates for the whole country has not been documented.

2.3 Requirements for African nightshade production

The vegetable is propagated through seeds and performs better in various climatic conditions, but grows best in cool, high moisture conditions for both medium and high altitudes (Abukusta-Onyango et al. 2004). Shaded conditions may cause a reduction in plant weight and fresh leaf yield. Nevertheless, African nightshade tolerates shade; it grows better when exposed to full sunlight with an annual rainfall of about 500–1200 mm. It grows in a variety of soils however requires more soil nutrients supplied externally if the soils are not fertile and is best adjusted to soils with high nitrogen, phosphorous and high in organic matter (Abukusta-Onyango et al. 2004). With usually shorter growing periods than other traditional crops, traditional vegetables can be less affected by environmental factors such as temperature and lack of moisture. The vegetables require small space than other crops, can optimize on readily available resources, well adapted to unfavorable environmental conditions easier to grow in comparison to their exotic vegetables (Tenkouano 2011).

African indigenous vegetables can produce seed under tropical conditions unlike the exotic vegetables. They have a short growth period with most of them being vegetables ready for harvesting within 3-4 weeks, and respond very well to organic fertilizers. African nightshade can withstand and tolerate some biotic and environmental stresses. They can also flourish under sustainable and environmental friendly cropping conditions like intercropping and use of organics.

2.4 importance African nightshade

Traditional vegetables contain high micronutrients contents, antioxidants (Yang and Keding 2009), and other health-related phytochemicals. The antibiotic, probiotic and prebiotic properties of vegetables can restore the balance of beneficial decomposing bacteria in the digestive tract (Veluri et al. 2004). Enhanced consumption of this vegetable and a more diverse of nutritious food help in addressing the saddle of problematic infections and diseases. Increased fruit and vegetable utilization is being promoted for their health benefits of phyto-chemicals associated with the prevention and controlling of problematic diseases (Steinmetz and Potter1996). African nightshade is used as medicine and remedy for hepato-megaly, spleno-megaly, edema, and gonorrhea, epilepsy, controlling diuretic, emmena-gogue and application for skin swellings, abscess, ulcers, and for gastric upsets. The vegetable also has medicinal values among African communities who use decoction and leave extract in some ethno medicinal preparations particularly majorly for dysentery treatment (Ambasta et al. 1992). African nightshade is nutritious, rich in β-carotene, minerals; iron, calcium and protein majorly methionine, and essential amino acid (Abukutsa-Onyango, 2004). African nightshade supply abundant amounts of protein, vitamins, calories and minerals that could help alleviate problems of malnutrition, poverty and lack of food in sub Saharan Africa. It is among the important traditional leafy vegetable consumed by various rural communities. With the introduction of exotic vegetables in Kenya, utilization of traditional vegetables declined hence narrowing down the vegetable food base and subsequently reduced vitamins, minerals and protein sources, which are usually available in vegetables (Abukutsa-Onyango, 2004).Vegetables are important in human diet in providing essential micronutrients which ensure health development of the human body (Abukutsa-Onyango, 2004).

African nightshade has considerable potential as cash income earner, enabling low income farmers in the rural communities to earn a living (Schippers, 2000, Onyango, 2003). Socio-economic survey on traditional vegetables conducted in various parts of Africa particularly in Central, Western and Eastern Africa (Abukutsa-Onyango, 2002; Schippers 2000) revealed that indigenous vegetables are important commodities in household food security. This will provide employment opportunities and generate income for the rural population.

Decline in consumption of traditional vegetables was due to a move towards exotic vegetables, which were perceived to be higher in nutritional, social values and high yielding. However, a problem of environmental deterioration, land fragmentation, more water requirements, diseases, pests and high prices of inorganic fertilizers have reduced reliability of exotic vegetables and have constricted down the availability of vegetable food base in most households especially the small holder farmers (Mwai et al. 2007).

2.5 Soil fertility

Increased crop productivity is the aim of every producer and cannot be achieved without effective nutrient management. The sole application of inorganic fertilizers has not been of much importance in vegetable production because it leads to soil degradation at long run, though they contribute to higher yield in comparison with organic manure alone. Continuous use of inorganic fertilizer as the main source of nutrients leads to rapid decline in crop yields because of acidification and soil compaction (Achieng et al. 2010). Permanent cultivation with no fertilizer application has been associated with soil fertility decline with reduced crop yields as a result. Reduction of crop yield is facilitated by decline of organic matter that automatically results in reduced soil pH, nutrient alteration leading to low crop yields. However, sole inorganic fertilizers applications can be problematic to humans and environment as well (Ayoola and Makinde, 2007). Subsequently, excessive usage of inorganic fertilizers by farmers to achieve high yield as they are considered a major source of plant nutrients leads to environmental and soil pollution.

There are several options for restoring and maintaining soil fertility for instance by integrating farm yard manure and mineral fertilizers and recycling part of the nutrients through use of manures or decomposed crop residues in the field so as to offset the nutrient removed by crops in the field and those which are lost via volatilization, leaching and run off (Aluko et al. 2014). The use of integrated organic manure and mineral fertilizers is a critical management strategy of soil fertility in most developing countries (Wen-Jie et al.2011). This is because it aims at alleviating the limiting nutrients and improves their availability from the soil reserves.

African nightshade is critical in food availability, nutrition and income creation. Small scale holder farmers produce low yields from African nightshade of about 3 tones ha^{-1} that is below the optimal levels of about 40 tones ha^{-1} (Abukutsa-Onyango et al., 2010). The decline in yields is caused by soil fertility deterioration majorly soil macro nutrients such as phosphorus, potassium, calcium and organic carbon. Supply of macronutrients should be supplied to the plants proportionally to maximize on yields (El Sheikha et al. 2016). Deficiency of soil Potassium has been shown to limit vegetable production in some parts of western Kenya, like Vihiga, Mumias and Kakamega (Gikonyo et al., 2003). 53% of small-scale farmers in these regions apply farm yard manure for improving African nightshade production (Ndinya 2003). Organic farm yard manure has significant amounts of potassium (Wanjekeche et al. 2003) and when combined with inorganic fertilizers hence the yield of African nightshades is improved compared to sole application of inorganic fertilizers (Aluka et al. 2014).

2.5.1 Farm yard manure

Farm yard manure has several advantages on the soil improvement and vegetable production. As an amendment for soil fertility, it can be applied as a source of external soil nutrients and mulch to raise temperatures of soils. It provides an option for weed control and be used in an integrated weed management strategy. Farm yard manure is generally environment friendly that can serve as an option strategy to control on use of mineral fertilizers as they aid in improving soil structure, soil organic carbon and microbial biomass (Suresh et al. 2004).They provide some quantities of major and micro nutrients resulting to an impact on soil over a long period. Even though few farmers have produced African nightshade with application of farm yard manure, no detailed study has been recognized for use by the wider small scale farmers in Kenya. Increased application of mineral fertilizers in sub Saharan Africa calls for a convenient intervention with high yields through sustainable production which can be obtained and maintained by promoting the application of organic manures though they have the limitation of being very low in nutrient content per unit weight compared to inorganic fertilizers and slow in their nutrient release (Ndinya 2003).

2.5.2 Inorganic fertilizers

There are abundant evidences that inorganic fertilizers can improve yield of crops significantly (Ojeniyi, 2002). Mineral fertilizers improves crop production and soil pH, total nutrient content, and availability of nutrients, however their application is minimal due to scarcity, high cost, nutrient imbalances and soil acidity (Akanbi et al. 2010).They may also facilitate indirectly to an increased soil microbial organisms by increasing the amount of crop remains returned to the soils, although the long-term application of inorganic nitrogen fertilizers may cause a decrease in microbial organism abundance and biomass. Total dependence on inorganic fertilizers however does not provide the panacea to soil management and crop productivity problems (Ojeniyi, 2002).Growers may apply excessive nitrogen pollution and nitrate accumulation in vegetables, hence posing health problems to consumers (Akanbi et al. 2010).

Limited agronomic technologies have been identified as a constraint facing African nightshade production. The use of nitrogen in increasing yields especially in traditional vegetables is a well-recognized practice. Soil nitrogen deficiency exerts its effects on plants through reduced leaf area index and hence low light interception and low dry matter production leading to low yields (Ndegwa et al. 2011). In addition, the leaf nitrogen content correlates well with the leaf chlorophyll content, hence nitrogen deficiency leads to reduced photosynthesis that results to low biomass accumulation (Zhao et al. 2005). Under limited nitrogen application, plants may respond by reducing leaf area and hence maintain the leaf nitrogen concentration which has been evident in Irish potato. Another strategy is to maintain a high leaf area, but adapt the leaf nitrogen concentration to nitrogen availability as demonstrated in maize (Vos et al. 2005). A clear indication of the response of African nightshades towards limited nitrogen supply is critical in the efforts to integrate them into the mainstream of vegetable production.

However, the most serious malnutrition effects are a result of inadequate utilization of vegetables rich in micronutrients usually referred to as hidden hunger. Micronutrient malnutrition results in impaired intellectual development, anemia, blindness, and mortality in children; and is accompanied with increased problems of cardiovascular diseases, diabetes, obesity and decreased worker productivity. The paradox is that while these malnutrition problems are prevalent, Kenya and other African regions on the continent are endowed with agricultural biodiversity (Schippers, 2000), which could significantly contribute to resolution of the problem. Therefore this study will heart on appropriate cropping systems and integrated nutrient management to address issues of environmental degradation, food security and economic empowerment. Intercropping will increase food base availability at affordable overheads while use of farm yard manure and inorganic fertilizer will cuddle environmental sustainability.

2.6 Intercropping

Intercropping is the cultivating of two or more crops in the same space and at the same time as commonly done by smallholder farmers (Seran & Brintha, 2010). It is known to make a more efficient use of growth factors as they capture and make a better use of radiant energy, available water and nutrients (Matusso et al. 2012). It also helps in effective utilization of land, soil moisture, nutrients and solar radiation. This is brought about by choosing appropriate vegetables of varying morpho-physiological nature and planning their planting geometry to reduce mutual competition for resources and enhance complementarities to increase overall productivity (Gurigbal, 2010). The low input and high risk environment of the smallholder farmer benefits enormously from intercropping that has an ability to combat erosion and raise soil fertility levels (Matusso et al. 2012). Flexibility, maximization of profit, minimization of risk, soil conservation and soil fertility improvement are some of the principal reasons for smallholder farmers to intercrop their vegetables (Matusso et al. 2012). Further to that, they have the potentials to give higher yield than sole crops, greater yield stability and efficient use of nutrients (Seran & Brintha, 2010). However, intercropping can lead to reduction in yield of component crop due to intense competition (Thole, 2007). But this can be overcome by basic morpho-physiological changes and agronomic features such as fertilizer application, sowing time, and proportion of crop mixture which are basic determinants of competition between component crops. Where constituent crops are arranged in certain rows, the degree of competition is determined by the comparative growth rates, growth duration and proximity of roots of the diverse crops (Thole, 2007). However, vegetable intercrops are greatest productive when the component crop varies greatly in growth duration so that their maximum condition for growth resources occurs at different periods (Ijoyah, 2012). Thus, the choice of accurate cultivars and agronomic manipulations to certify the most effective use of limiting resources is key part for high crop yield (Thayamini & Brintha, 2010).

2.7 Monitoring Nutrient flows

Over a decade in sub-Saharan Africa, more attention has been given in estimation and quantification of nutrients flows in the agricultural fields. In many areas of Kenya soil fertility levels tend to decline further as farmers are mining nutrients through harvested products, crop residues and nutrient losses through leaching, gaseous losses and soil erosion (Lesschen et al. 2003). The capacity of soil reservoir to perform the critical function to support crop production is undergoing degradation and deterioration due to nutrient depletion hence soil fertility levels should be monitored to provide early caveat on adverse trends which ultimately enable farmers to implement target interventions (Kathuku et al. 2007).

Nutrient monitoring is a method of quantifying nutrient inflows and outflows resulting in nutrient balance. The nutrient balances determined at individual level activities at farm level serves as a useful indicator to provide an insight on nutrient losses (Vlaming et al. 2001). Farm NUTMON tool integrates assessment of stocks and flow especially Nitrogen, Phosphorous and Potassium (Kathuku et al. 2007). The tool calculates flows and balances of macro-nutrients through independent assessment of major inputs and outputs. It is based on a set of five inflows and five outflows (IN 1-5; mineral fertilizer, organic fertilizer, atmospheric deposition, biological nitrogen fixation and sedimentation, OUT 1-5 harvested products, removal of crop residues, leaching, gaseous losses and erosion (Vlaming et al. 2001). Thus NUTMON provides a quick method for monitoring agricultural technologies employed by farmers.

CHAPTER THREE

EFFECTS OF INTERCROPPING ARRANGEMENTS AND FERTILIZER APPLICATION ON GROWTH AND YIELD OF AFRICAN NIGHTSHADE (*solanum nigrum* L.)

Abstract

The study evaluated the effects of intercropping arrangements and fertilizer combinations on growth and yields of ANS (*Solanum nigrum* L.). The study was carried at Kenya Agricultural and Livestock Research Organization in Kisii County. The experiments were laid out in a complete randomized block design with a split plot arrangement replicated thrice. The main plots were intercropping arrangements of spider plant: African nightshade rows and sub plots were fertilizer combinations of Farm yard manure (FYM), urea and triple super phosphate (TSP).Data on the number of branches per plant; number of leaves per plant, and total fresh leaf yield were measured. Fertilizer combinations had a significant (P=0.05) effect on number of branches and leaves per plant. Application of urea (60kg N ha^{-1}) +TSP (40kg P ha^{-1}) resulted in the highest number of branches and leaves (10 branches and 32 leaves per plant) while the sole application of FYM (60kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest number of branches and leaves per plant (6 branches and 21 leaves per plant). On total fresh leaf yield, the results indicated that there was a significant (P=0.05) interaction between intercropping arrangements and fertilizer combinations. Sole African nightshade supplied with Urea(60kg N ha^{-1}) + TSP(40Kg P ha^{-1}) resulted in the highest total fresh leaf yield (35.1 tons ha^{-1}) which was not significantly different from sole ANS supplied with urea (40 kg N ha^{-1}) + TSP (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-}1) that obtained 32.5 tons ha^{-1}. Therefore to boost ANS production, an application of urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) combined with intercrop ratio of 1:14 will be the most appropriate production package. But for those farmers who prefer to grow sole African nightshade, then a combination of urea (40 kg N ha^{-1}) + TSP (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) will be the most appropriate to boost the fresh leaf yield of the vegetable.

Keywords: number of branches, number of leaves, total fresh leaf yield

---

Published in the international journal of Agriculture and Environmental Research Vol 2 (5): (Pg 1069-1083) (2016).

3.1 Introduction

African nightshade is one of the leafy vegetables in the *solanaceae* family, largely domesticated in sub-Saharan Africa (Abukusta-Onyango et al. 2004). It is known because of its nutritional, medicinal value and a source of livelihood; rich in iron, calcium vitamins A and C (Yang et al. 2009). African nightshade is a valuable source of nutrients and income generation for small-scale farmers in sub-Saharan Africa and is incorporated in the main meals for urban inhabitants. Consumption, demand, and market value of this vegetable have rapidly and steadily risen as consumers become aware of their nutritional, economical and medicinal values. In recent years, the resurgence in popularity has prompted rapid domestication and commercialization of nightshade production, from subsistence to commercial farming on contract for municipal, urban, super markets and hotel chains (Abukutsa-Onyango 2003; Mwai and Schippers 2004).

The vegetable is normally grown in home gardens and usually intercropped with other vegetables or cereals like maize, sorghum or millet (Obuoyo, 2005). It has been shown that the nutrient content of the vegetable is sufficient in providing daily allowance of nutrients for people in terms of iron, calcium, b-carotene, ascorbic acid and protein (Abukutsa-Onyango, 2003).

African nightshade has not been exploited fully in terms of food, nutrition and economically in an endeavor to eradicate poverty. Some of the main hindrances in production of this Vegetable include poor seed quality, low yields and poor marketing and dispensation strategies. The cultivation of this vegetable is dynamic, ecologically based natural resource conservation whose presence or lack of it depends on human activity, local knowledge and their culture (Maffi and Woodley, 2010). The African nightshade is characterized by fast growth, tolerance to ecological conditions and provision of nutrients (Adebooye and Opabote, 2004). With intensified commercial agriculture and increased population, among other factors, more land is converted to commercial agricultural production at the expense of the indigenous vegetables (Netondo et al. 2010) consequently eroding the diversity of this vegetable.

Soil fertility and plant nutrition are important aspect of cropping system and these include adequate supply of essential nutrients for soil productivity, plant nutrition and qualitative crop yield (Chang et al. 2014). The availability of these nutrients to plant contributes a lot to its growth and yield but deficiency of mineral elements essential for plant crop is evident in poor yield and yield quality (Yang et al. 2012). Adequate supply of mineral elements is of importance in the tropics where the soil is poorly formed and continuous cropping is on the increase, however any sustainable crop production, soil fertility amelioration is essential (Aluko et al. 2014).

Adequate soil fertility is essential for sustainable vegetable production. Tropical soils are inadequate in soil nutrients. Thus, the application of fertilizer or manure for amelioration of soil fertility is an integral part of leafy vegetable production (Aluko et al. 2014). Leafy vegetables require nitrogen for good vegetative growth (Kipkosgei et al. 2003). The quality of the harvest and storability are influenced by the availability of essential minerals in balanced proportion. Any deviation from the balanced proportion of nutrients is easily noticed on the leaves of vegetable crops as deficiency symptoms hence reduced crop yield.

In addition, African nightshade production has been shown to be constrained by pests and diseases which severely impact the quantity and quality of its yield (Hassan et al., 2010) causing between 5 -12% yield losses (Sikora and Fernandez, 2005). Disease incidence of up to 60% on African nightshade in parts of Kenya affects the yield and growth of vegetables. Pests and diseases lead commonly to an overuse of chemical pesticides in small scale and commercial production systems, causing well-known toxicological and environmental problems (Sikora and Fernandez, 2005). More sustainable integrated pest and disease management is therefore a high priority, furthering the production of healthy vegetables are important sources of human nutrients and household incomes.

Intercropping vegetables with other crop species is increasingly gaining popularity as a potential alternative to the use of chemicals (Trdan et al. 2005a, b; Trdan 2006). Intercropping with commonly used vegetable crop fits into environmentally acceptable and sustainable crop production practices widely adopted by smallholder farmers. This concept entails growing two or more economic species together for at least a portion of their respective productive life cycle, planting them sufficiently close to each to allow for inter-specific competition (Kabura et al. 2008). Benefits of intercropping include; optimal use of resources, stabilization of yield, weed suppression, improved soil fertility conservation and higher economic returns (Blaser et al. 2007; Trdan et al. 2005a; Kabura et al. 2008).The aim of the study was therefore to investigate effects of intercropping arrangements and fertilizer combinations on growth and yield of African nightshade.

3.2 Materials and methods

3.2.1 Site description

The study was conducted at KALRO, Kisii County, Kenya between February 2015 and February 2016. Kisii County lies between Longitudes: 34° 46' E and Latitudes: 0° 41' S. It receives a bimodal type of rainfall with both long and short rain season having a mean of 1500mm p.a. The long rains are received between March and June with a mean of 790mm and the short rains are received between September and November with a mean of 500mm. The area experiences a maximum temperatures of 30^{o}C and minimum temperatures of 15^{o}C. The soils are well drained with (nitsols) with large amounts of organic matter (Soil handbook of Kenya 2000). Main economic activities of the inhabitants are crop farming, small scale trade, dairy farming, commercial businesses and soapstone carvings.

3.2.2 Experimental design and treatments

The experiment was laid in a randomized complete block design with three replications with a split plot arrangement replicated three times. The main (4.8 by 11m) plots consisted of intercropping arrangements;(i) sole African nightshade, (ii) spider plant surrounding 14 rows of African nightshade (1:14),(iii) one row of spider plant intercropped with 2 rows of African nightshade (1:2), (iv) one row of spider plant intercropped with 3 rows of African nightshade (1:3) and (v) one row of spider plant intercropped with 4 rows of African nightshade (1:4). In the sub plots (4.8 by 1.8m),fertilizer combination were; (i) pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}), (ii) pure inorganic fertilizer- urea (60 kg N ha^{-1}) + TSP (40 kg P ha^{-1}), (iii) urea (30 kg N ha^{-1}) + TSP (20 kg P ha^{-1}) + FYM (30 kg N ha^{-1}+ 18 kg P ha^{-1}), (iv) urea (20 kg N ha^{-1})+ TSP (10 kg P ha^{-1}) + FYM (40 kg N ha^{-1}+ 27 kg P ha^{-1}), (v) urea (40 kg N ha^{-1}) + TSP (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}).At planting urea and tri-superphosphate were banded together while farm yard manure was applied two weeks prior to planting at rates that depended on the treatment for each plot.

3.2.3 Agronomical practices

The plots were ploughed and harrowed before planting using hand hoes. Furrows were made and five seeds of both spider plant and African nightshade (depending on the intercrop arrangement) were sown directly at a spacing of 30 cm x 15 cm and thereafter thinning was done to one plants per hole giving a total of 16 rows per plot. Hand weeding was done regularly to ease competition from weeds and the crop solely depended on rainfall.

3.2.4 Data collection

Five plants from each sub plot were tagged for data collection on number of branches, number of leaves and the total leaf yield. Data collection for all variables started at week five after planting and continued on a weekly basis for a period of seven weeks when crop yields declined. The number of branches per plant was recorded by counting the number of branches from each five tagged plants and the mean was taken while the number of leaves per plant was determined by counting fully expanded leaves from each of the five tagged plants and the mean was taken. For the total leaf yield from all the five tagged plants were harvested and weighed using an electronic weighing balance and the mean was used to calculate total fresh leaf yield per plot given the number of plants in the plot which was then converted to fresh leaf yield per hectare.

3.3 Data Analysis

Data was subjected to analysis of variance (ANOVA) using GENSTAT version 15. (Payne et al. 2011) and means were separated using Fisher's protected LSD at 5% to identify differences between treatments.

3.4 RESULTS

3.4.1 Number of branches

There were no significant interaction effects of intercropping arrangements and fertilizer combinations however results indicated that fertilizer combinations had a significant (P=0.05) effect on the number of branches per plant (Table 3.1).

Table3.1: Effects of fertilizer combinations on the number of branches per plant of African nightshade (*Solanam nigrum* L)

Fertilizer Combinations	No. of branches/plant
60kgN/ha urea + 40kgP/ha TSP	10a
40kgN/ha urea + 30kgP/ha TSP +20kgN/ha FYM	9b
30kgN/ha urea + 20kgP/ha TSP +30kgN/ha FYM	7c
20kgN/ha urea + 10kgP/ha TSP +40kgN/ha FYM	7c
60kgN/ha farm yard manure	6d
LSD = 0.4 CV= 6.9	

N=5. Means followed by the same letter along a column are not significantly different (P≤0.05).

Application of urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) fertilizer resulted in the highest number of branches per plant (10 branches per plant) followed by fertilizer combination of urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) that recorded 9 branches per plant, urea (30 kg N ha^{-1}) + triple superphosphate (20 kg P ha^{-1}) + FYM (30 kg N ha^{-1}+ 18 kg P ha^{-1}) and urea (20 kg N ha^{-1}) + triple superphosphate (10 kg P ha^{-1}) + FYM (40 kg N ha^{-1}+ 27 kg P ha^{-1}) both of which recorded 7 branches per plant

(Table 3.1).The application of pure FYM(60kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest number of branches per plant (6 branches per plant) (Table 3.1).

Similarly, intercropping arrangement had a significant (P=0.05) effect on the number of branches per plant (Table 3.2). The highest number of branches per plant (9 branches per plant) was obtained when African nightshade was grown as a pure stand. However, this was not significantly different from the number of branches obtained when African nightshade was grown at an intercrop ratio of 1:14 (spider plant as border rows), 1:3 and 1:4 that resulted in 8 branches per plant (Table 3.2).

Table3.2: Effects of intercropping arrangements on the number of branches of African nightshade (*Solanum nigrum* L.)

Intercrop row arrangement	Number of branches/plant
Sole African nightshade	9a
Spider plant: African nightshade 1:14	8ab
Spider plant: African nightshade1:3	8ab
Spider plant: African nightshade 1:2	7b
Spider plant: African nightshade 1:4	8ab
LSD = 1.0 CV= 7.5	

N=5. Means followed by the same letter(s) along a column are not significantly different (P≤0.05).

Growing of African nightshade at an intercrop ratio of 1:2 recorded significantly lower number of branches per plant (7 braches per plant).However, this was not statistically different from the number of branches per plant obtained when African nightshade was grown at intercrop ratios of 1:14, 1:3 and 1:4 (Table3.2).

Treatments with higher rates of inorganic fertilizer resulted in higher number of branches per plant compared to treatments with pure farm yard manure. The nitrogen and phosphorous from the inorganic fertilizer have been shown to be more readily available for plant uptake compared to that supplied by farm yard manure (Powlsen et al. 2014). Nitrogen is an essential element and important determinant in growth and development of vegetables. It plays an important role in chlorophyll, protein, nucleic acid, hormone and vitamin synthesis and also helps in cell division and cell elongation hence facilitates more shoot formation (Miller, 2010).Adequate supply of phosphorus early in plant life is important in laying down the primordial for plant growth. It is also an essential constituent of majority of enzymes which are responsible in the transformation of energy in carbohydrate metabolism, fat metabolism and also in respiration that stimulates shoot formation in vegetables (Fink et al. 1999). Therefore with synergetic influence of nitrogen and phosphorus, there is a possibility of more photosynthates being allocated for new branch formation. This therefore can be attributed to the high number of branches recorded in this study when a combination of urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) or urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM(20 kg N ha^{-1}+ 9 kg P ha^{-1}) fertilizer was applied. Gambo et al. (2008) working with onion; Babajide et al. (2008) working with tomato and Mahadeen and Ouda, (2008) working with broccoli reported that the use of pure farm yard manure results in reduced number of branches while incorporation `of organic and inorganic fertilizers results in more branches per plant. Similarly, Kopkosgei et al. (2003) working on fertilizer application on African nightshade reported that a combination of farm yard manure and inorganic fertilizer in which, the percentage of the inorganic fertilizer is higher than that of the organic fertilizer increases the number of branches produced per plant.

In addition, intercropping arrangements significantly influenced the number of branches of African nightshade. The sole African nightshade obtained higher number of branches compared to all other intercrop ratios. This could be due to below and above ground competition between spider plant and African nightshade for available soil nutrients, space, light and CO_2. It could be possible that there was completion of available nutrients by the two crops and reduced number of branches of African nightshade per plant. Besides, plant architecture plays an important role for shoots in intercropping arrangements (Liu et al. 2010). Spider plant and African nightshade have different architecture and growth habits which could be the reason for decreased number of branches compared to sole African nightshade. These results agree with those of Schnieders (1999) working with *Solanum nigrum* intercropped with Witloof chicory that showed that African nightshade at a ratio of witloof chicory: *Solanum nigrum* (1:2) produces less number of branches per plant compared to the respective mono crops.

3.4.2 Number of leaves

The results indicated that fertilizer combinations had a significant (P=0.05) effect on the number of leaves per plant (Table 3.3). Application of urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) resulted in the highest number of leaves (32 leaves per plant). However this was not statistically different from application of urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) that resulted in 31 leaves per plant, followed by a combination of urea (30 kg N ha^{-1}) + triple superphosphate (20 kg P ha^{-1}) + FYM (30 kg N ha^{-1}+ 18 kg P ha^{-1}) that recorded 27 leaves per plant (Table 3.3). An application of FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest number of leaves (20 leaves per plant). This was not significantly different from the number of leaves per plant that resulted from a combined application of urea (20 kg N ha^{-1}) + triple superphosphate (10 kg P ha^{-1}) + FYM (40 kg N ha^{-1} + 27 kg P ha^{-1}) that resulted in 20 leaves per plant (Table 3.3).

Table3.3: Effects of fertilizer combinations on the number of leaves/plant of African nightshade (*Solanam nigrum* L)

Fertilizer Combinations	No. of leaves/plant
60kgN/ha urea + 40kgP/ha TSP	32a
40kgN/ha urea + 30kgP/ha TSP +20kgN/ha FYM	31a
30kgN/ha urea + 20kgP/ha TSP +30kgN/ha FYM	27b
20kgN/ha urea + 10kgP/ha TSP +40kgN/ha FYM	21c
60kgN/ha farm yard manure	20c
LSD = 1.82 CV= 9.7	

N=5. Means followed by the same letter along the column are not significantly different ($P \leq 0.05$).

The results further showed that intercropping arrangement had a significant (P=0.05) effect on the number of leaves per plant (Table 3.4). The highest number of leaves (29 leaves per plant) was obtained when African nightshade was grown as a pure stand. However this was not significantly different from 27 leaves per plant that was obtained when African nightshade was grown at an intercrop ratio of 1:14 (spider plant as border rows) (Table 3.4). This was followed by intercrop ratios of 1:4 and 1:3 that resulted in 26 leaves and 25 leaves per plant respectively, however they were not significantly different when African nightshade was grown at an intercrop ratio of 1:14 (Table 3.4). Besides, growing African nightshade at an intercrop ratio of 1:2 recorded the lowest number of leaves per plant (20 leaves per plant).

Table3.4: Effects of intercropping arrangements on the number of leaves/plant of African nightshade (*Solanum nigrum* L.)

Intercrop row arrangement	**Number of leaves/plant**
Sole African nightshade	29a
Spider plant as border rows 1:14	27ab
Spider plant: African nightshade1:3	25b
Spider plant: African nightshade 1:2	20c
Spider plant: African nightshade 1:4	26b
LSD = 2.87 CV= 6.0	

N=5. Means followed by the same letter(s) along a column are not significantly different ($P \leq 0.05$).

Treatments with higher rates of inorganic fertilizer resulted in higher number of leaves per plant compared to treatments with pure farm yard manure. Nitrogen is an essential element required for successful plant growth. Application of inorganic and farm yard manure increases the nitrogen, phosphorus, and potassium content in soil (Watts et al. 2010). These nutrients are essential constituents of majority of enzymes which are responsible in the transformation of energy in carbohydrate metabolism, fat metabolism and also in respiration that stimulates leave formation in vegetables (Fink et al. 1999). Besides, phosphorous is a constituent of nucleic acid, phytins and phospholipids (Ndakemi and Dakora, 2007). Research has also been shown that there exists a synergetic effect of inorganic fertilizers and farm yard manure in facilitating new leaf formation. This therefore can be attributed to the high number of leaves recorded in this study when combination of urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) or urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) fertilizer was applied. Makinde et al. (2013) working on amaranths, reported that inorganic fertilizer results in a high number of leaves per plant, however, a combination of inorganic fertilizer and organic fertilizer at the ratio of 2:1 (inorganic: organic) for the supply of nitrogen in this study resulted in number of leaves per plant that was not significantly different from that obtained when pure inorganic fertilizer was used. The complementary application of organic and inorganic fertilizers has been found to meet the immediate soil nutrient deficits, improve the soil physical properties and enhance yield stability (Aluko et al. 2014).

Further, intercropping arrangements significantly influenced the number of leaves of African nightshade. The sole African nightshade and 1:14 intercrop ratio obtained higher number of branches compared to other intercrop ratios. This could be attributed to below and above ground competition for light, nutrients, space and CO_2. However, growth synchronies as well as canopy design could be also the main mechanisms that contributed to this intercropping performance. These results agree with the findings of Santos et al. (2002) working on broccoli, who reported that intercropping broccoli with cauliflower results in reduced number of leaves compared to mono crops. Besides, Matusso et al. (2014) working with soybean -maize intercrop reported that maize mono crop intercepted more light and hence higher number of leaves and leaf index area. However it has been reported that a greater yield advantage can be realized when the component crops have complementary growth patterns in terms of growth rate, maturity, and plant architecture (Ghosh et al. 2006).

3.4.3 Total fresh leaf yield

The results showed that there was a significant (P=0.05) interaction between fertilizer combinations and intercropping arrangements on total fresh leaf yield of African nightshade (Tables 3.5).The sole African nightshade (0:16) supplied with fertilizer combination of urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) resulted in the highest leaf yield (35.1 tons ha^{-1})that was not significantly different from that obtained when African nightshade was supplied with urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) (32.5 tons ha^{-1}) at the same intercropping arrangement (Table 3.5).

Table3.5: Effect of intercropping arrangements and fertilizer combination on fresh leaf yield (tons /ha) of African nightshade (*Solanum nigrum*L.)

Fertilizer combinations	**FRESH LEAF YIELD (tons ha^{-1})**				
	Intercropping arrangements (Spider plant: African nightshade				
	Sole ANS	**1:14(SP as border)**	**1:3**	**1:2**	**1:4**
60kgN/ha urea + 40kgP/ha TSP	35.1a	29.3bc	21.8ef	18.2fgh	23.8de
40kgN/ha urea + 30kgP/ha TSP +20kgN/ha FYM	32.5ab	27.3cd	21.3efg	15.9hij	23.5de
30kgN/ha urea + 20kgP/ha TSP +30kgN/ha FYM	21.7efg	17.8ghi	15.0hijk	11.8kl	16.4hi
20kgN/ha urea + 10kgP/ha TSP +40kgN/ha FYM	18.7fgh	17.3hi	14.0ijk	10.0l	15.9hij
60kgN/ha farm yard manure	15.8hij	15.1hijk	12.2jkl	8.9l	9.2l
LSD= 3.8585 CV= 10.8					

N=15. FYM-farm yard manure, TSP-Triple superphosphate, Means followed by the same letter(s) is not significantly different (P≤0.05).

This was followed by an intercrop ratio of 1:14 (spider plant grown on the border rows) supplied with either urea (60kg N ha^{-1}) +triple superphosphate (40kg P ha^{-1}) that produced 29.3 tonsha^{-1}or supplied with urea (40kg N ha^{-1}) + triple superphosphate (30kg P ha^{-1}) + FYM (20kg N ha^{-1}+ 9 kg ha^{-1}) that produced 27.3 tonsha^{-1}. A further increase in the plant population of spider plant and/or the amount of FYM used in the production resulted in significantly (P=0.05) lower total fresh leaf yield (Table 3.5). Growing of African nightshade at an intercrop ratio of 1:2 supplied with pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest fresh leaf yield (8.9 tons ha^{-1}) however this was not significantly different from 1:3 and 1:4 intercrop ratios with the same fertilizer combinations that recorded 12.2 tons ha^{-1} and 9.2 tons ha^{-1} respectively (Table 3.5). In addition, intercrop ratios of 1:3 and 1:4 did not differ significantly across the fertilizer combinations.

Intercropping arrangements and fertilizer combinations greatly influenced the total fresh leaf yield. During growth and development, vegetable plants intercept and absorb light, water and nutrients and use them to produce biomass (Mohamed et al. 2007). Part of this biomass is the harvestable yield. The factors that affect growth are distributed in space and time. Complementary and supplementary relations between crops determine the magnitude of intercrop competition (Ofori and Gamedoaghao, 2005). Farm yard manure is a slow release of soil nutrients for plant uptake; however the residual benefits of farm yard manure on the soil physical and biological properties cannot be under estimated. In this study, African nightshade as pure stand supplied with either urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) or urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) recorded the highest total fresh leaf yield. However, intercrops with more rows of spider plant across fertilizer combinations recorded low yields compared to sole African nightshade. This could be attributed to competition for available nutrient base, CO_2 and light interception. These results agree with those of Mohamed et al. (2007) working on okra, who reported that intercropping okra with cucumber significantly reduces the fruit yield of cucumber compared to the respective mono crops. In addition, Kipkosgei et al. (2003) working on African nightshade reported that synergetic effect of inorganic and organic fertilizer increases African nightshade leaf yields. Further, Mahadeem et al. (2008) working on broccoli, reported that inorganic fertilizer produces the highest yields compared to the corresponding amounts of organic manure, however combined fertilizer application produces comparably higher yields as pure inorganic fertilizer. Similarly, low yields exhibited in 1:2, 1:3 and 1:4 intercrop row ratios when supplied with only farm yard manure as compared to sole African nightshade could be associated with inter-specific competition for nutrients, moisture space and slow mineralization rate of farm yard manure (Adani et al. 2007). Further, Olufajo (1992) reported that shading by taller plants in intercrops reduce the photosynthetic rate of the lower growing plants and thereby reduce their yields. However it was noted that farmers can use pure farm yard manure over a fertilizer combination of urea (20 kg N ha^{-1}) + triple superphosphate (10 kg P ha^{-1}) + FYM (40 kg N ha^{-1}+ 27 kg P ha^{-1}) across intercropping arrangements to cut extra cost of production as there was no yield advantage gained at this fertilizer combination rates. Even though there was no yield benefits exhibited in African nightshade after intercropping with spider plant, there is a possibility that the combined yield obtained from different spider plant: African nightshade intercropping system for both vegetables could be greater than for the mono-cropped African nightshade. In addition, 1:4 and 1:3 intercrop ratios may be more important to the farmer in terms of income diversification and diversity in crops available for both food and nutrition needs when compared to sole African.

3.5 Conclusion

The spider plant- African nightshade fertilizer combinations and intercropping arrangements influenced the growth and yield of African nightshade. Fertilizer combinations influenced the number of branches and leaves per plant with application of Urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) recording a high number of branches and leaves per plant that was comparable to when Urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) was used. Intercropping arrangements reduced the number of branches and leaves compared to sole African nightshade. Further, high total fresh leaf yield was produced when sole African nightshade and intercropping of Spider plant and African nightshade at a ratio of 1:14 (spider plant as border rows) supplied with either urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) or Urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM(20 kg N ha^{-1}+ 9 kg P ha^{-1}) was used in the production of the vegetable.

CHAPTER FOUR

INFLUENCE OF COMBINED FERTILIZER APPLICATION AND SPIDER PLANT (C*leome gynandra*) INTEGRATION IN AFRICAN NIGHTSHADE (*Solanum nigrum* L.) PRODUCTION ON SOIL NUTRIENT STATUS AND BALANCES

Abstract

Calculation of soil nutrient balances and soil nutrient status is imperative in establishing innovative sustainable technologies in soil fertility and farm productivity. This study investigated the influence of combined fertilizer application and integration of spider plant in African nightshade cropping system on soil nutrient status and balances. The study was carried out at the Kenya Agricultural and Livestock Research Organization, Kisii County. The experiments were laid out in a complete randomized block design with a split plot arrangement replicated thrice. The main plots were intercropping arrangements of spider plant: African nightshade rows and sub plots had fertilizer combinations of Farm yard manure (FYM), urea and triple super phosphate (TSP).Soil pH, Soil Organic carbon, N, P and K were determined after the harvest of the vegetable and N, P, K balances were calculated at plot level using nutrient monitoring (NUTMON) Tool box. Intercropping arrangements and fertilizer combinations had a significant (P=0.05) effect on soil nutrient status and balances. On nutrient status, soil nitrogen from plots containing intercrop ratio of 1:14 supplied with FYM (60 kg N ha^{-1}+ 36kg P ha^{-1}) recorded 0.46% N that was not statistically different from 1:3 intercrop ratio or sole ANS supplied with the same fertilizer while an intercrop ratio of 1:2 supplied with urea (40 kg N ha^{-1})+ triple superphosphate (30 kg P ha^{-1})+FYM (20 kg N ha^{-1}+ 9kg P ha^{-1})or urea (60 kg N ha^{-1})+ triple superphosphate (40 kg P ha^{-1}) resulted in 0.3% N and a phosphorus content of 11.7ppm. Further, sole African nightshade, intercrop ratios of 1:3 1:4, and 1:14 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded 8 cmol P kg^{-1} while those supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) or urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1})recorded 4 cmol P kg $^{-1}$ across all intercropping arrangements. Further, plots containing sole African nightshade, 1:3, 1:14 and 1:4 intercrop ratios supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded 3 % C. In addition, plots containing sole African nightshade and those with intercrop ratio of 1:4 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded the highest soil pH of 6.3 after harvest. On nutrient balances, sole African

nightshade supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded negative nutrient balances of -9 kg N, -9.9 kg P and -5.4 kg K ha^{-1} yr^{-1}while an intercrop ratio of 1:2 supplied with an application of urea (60 kg N ha^{-1})+ triple superphosphate (40 kg P ha^{-1}) recorded negative nutrient balances of -36.5 N, -25.2 P and -34.2 kg K ha^{-1} yr^{-1}. It can therefore be concluded that production of ANS as sole crop or at intercropping ratios of 1:3, 1:14 and 1:4 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) leads to an increase soil organic carbon and soil pH. This can be an important production system to incorporate in managing soils with increased acidity and reduced soil carbon to improve soil productivity.

Keywords: nutrient balances, intercropping arrangement, NUTMON

4.1 Introduction

Soil fertility replenishment in Sub-Saharan Africa is vital to the process of poverty alleviation (Place et al. 2003). Increased agricultural productivity and improved livelihoods won't occur without investing in soil fertility (Place et al. 2003). Over the last few years, much attention has been given to the quantification and estimation of nutrients that flows through agricultural systems (Lesschen et al. 2003).Soil nutrient mining is the root cause of declining land productivity especially in small holder farming systems (Mugendi et al. 2003). In western region, low soil fertility tends to decline further, as farmers remove nutrient through outputs in crops, crop residues and through losses by leaching, and soil erosion. Nutrients lost through harvestable products, particularly nitrogen and phosphorus are not sufficiently replenished because of high cost of inorganic fertilizers(Gachimbi et al. 2002) and this definitely will sham a risk of food shortages in the predominantly low-input agricultural systems (Mtei et al. 2013).

Constraints to inorganic fertilizers in sub Saharan Africa christens for exploration of inorganic fertilizer reduction by substituting with alternate means to convene the nutrient requirements of crops without any significant decrease in yield (Mutala, 2012). Use of inorganic fertilizers, farm yard manure and intercropping systems are biased towards their influence on soil fertility and crop yield improvement assume environmental and socio-economic effects they pose. Integrated soil fertility management thus encompasses multiple factors and effects such as biological, physical, chemical, economic and political aspects of soil fertility deterioration (Place et al. 2003). It provides a wide choice use of both farm yard manure and inorganic fertilizer inputs to smallholder farmers, but many farmers are still staggering on how much of organic and mineral fertilizers to apply. Leafy vegetables require higher quantities of nitrogen compared to other primary nutrients supplied by the farmers (Epstein and Bloom, 2005) of which the plant nutrition of crops is based on supply from native soil nutrient pool and other additions from farm yard manure (Gachimbi et al. 2002).

There are very close relationships between yield advantage and nutrient acquisition in intercropping systems which is an efficient cropping system in terms of resource utilization (Zhang et al. 2004). Furthermore, intercropping also provides an important pathway to reduce soil erosion, fix atmospheric N_2, lower the risk of crop failure or disease and increase land use efficiency (Li et al. 2013). However, nutrients lost through harvested products, especially nitrogen (N) and phosphorus (P) are not adequately replenished due to high prices of inorganic fertilizers (Gachimbi et al. 2002)

Assessing the impact of agricultural technologies on soil fertility and future sustainability, nutrient balance calculation is necessary (Vlaming et al. 2001). NUTMON, a nutrient monitoring tool, is used to determine balances of N, P and potassium (K) in soil (Onwonga et al. 2008). Farm-NUTMON is a tool that integrates the assessment of stocks and flows of nitrogen, phosphorus and potassium and economic farm analysis. It estimates the extent to which farmers generate income through soil nutrient mining, assesses the impact of farm management change techniques on nutrient balance and economic performance at activity level and farm level, and determines the economic impact of exogenous changes on the farm and activity level (Van den Bosch et al. 1998). Hence NUTMON assesses the amounts of both organic and mineral fertilizer inputs a farmer uses and nutrient losses through crop harvests, removal of crop residues, leaching, gaseous losses and erosion. Against this milieu, the study investigated the influence of integrated African nightshade with spider plant and fertilizer combination on soil nutrient status and balances.

4.2 Materials and methods

4.2.1 Site description

The study was conducted between February 2015 and February 2016 at KALRO, Kisii County, Kenya (longitudes: 34° 46' E, latitudes: 0° 41' S and altitude: 1700m above sea level. It receives average annual rainfall of 1500mm with the long rains between March and June while the short rains are received from September to November. The maximum and minimum temperatures range between 21°C – 30°C and 15°C – 20°C respectively. The soils are well drained with (nitsols) with large amounts of organic matter (Makone et al. 2015).

4.2.2 Experimental design and treatments

The experiment was laid out in a randomized complete block design with a split plot arrangement replicated three times. The main (4.8 by 11m) plots consisted of intercropping arrangements;(i) sole African nightshade, (ii) spider plant surrounding 14 rows of African nightshade (1:14),(iii) one row of spider plant intercropped with 2 rows of African nightshade (1:2), (iv) one row of spider plant intercropped with 3 rows of African nightshade (1:3) and (v) one row of spider plant intercropped with 4 rows of African nightshade (1:4). In the sub plots(4.8 by 1.8m),fertilizer combination were; (i) pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}), (ii) pure inorganic fertilizer- urea (60 kg N ha^{-1}) + TSP (40 kg P ha^{-1}), (iii) urea (30 kg N ha^{-1}) + TSP (20 kg P ha^{-1}) + FYM (30 kg N ha^{-1}+ 18 kg P ha^{-1}), (iv) urea (20 kg N ha^{-1})+ TSP (10 kg P ha^{-1}) + FYM (40 kg N ha^{-1}+ 27 kg P ha^{-1}), (v) urea (40 kg N ha^{-1}) + TSP (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}).

4.2.3 Agronomical practices

The plots were ploughed and harrowed before planting using hand hoes. The seeds were sowed directly at a spacing of 15cm between plants and 30cm between rows giving a total of 16 rows. At planting urea and tri-superphosphate were banded together while farm yard manure was applied two weeks prior to planting to those plots that were receiving both inorganic fertilizer and farm yard manure. Hand weeding was done regularly to ease competition from weeds and the crop solely depended on rainfall.

4.2.4 Soil sampling and analyses

4.2.4.1 Soil sampling

Soil samples were picked at a soil depth of 0 - 20 cm collected in a zigzag manner from the experimental plots before planting and at the end of the crop harvest. , From each plot, soils were picked from five points, mixed and a subsample of 250g picked for the analyses. The samples were kept in polythene bags and transported in portable cool boxes to the laboratory for analysis of soil nutrient N, P, K as well as pH and soil organic carbon (C).

4.2.4.2 Sample preparation and analysis

The soil samples were air-dried and ground to pass through 2 mm sieve ready for analysis. The pH was determined by following Catherine and Parent (2002). The soil P^H was determined using one part of soil to 2.5 parts of water then the mixture was allowed to come into equilibrium for the suspension to settle. The reading was taken by lowering the P^H meter into the solution. Soil organic carbon was determined using the Black-Walkley (Black et al. 1965). 0.5g of the dried soil samples was mixed with 10ml of potassium dichromate followed by an addition of 15ml of conc. Sulphuric acid. 5ml H_3PO_4 was added after the addition of 200ml 0f water and 2-3 drops of phenanthroline indicator then titration was done with 0.5N $FeSO_4$.Nitrogen was determined by micro Kjeldahl method (Okalebo et al. 2002). 1g of air dried soil sample was mixed with the catalyst and concentrated Sulphuric acid in a Khejdahl digestion block at the temperatures of 120^0c for one hour then followed by 360^0c for two hours. Addition of 10mls of 40% of sodium hydroxide and distillation was done into the 2%boric acid followed by titration of the green colored solution with 0.01N sulphuric acid where the mixed indicator turned from green to light pink marking the end point. Phosphorus and potassium were determined using the double acid method (Okalebo et al. 2002) and Flame Emission Spectrophotometer (Jońca and Lewandoski, 2004) respectively. 5g sample of each soil was weighed into a 100ml extracting tube. A 50ml double acid reagent was added and the mixture was shaken mechanically using a machine for 30 minutes then filtered using the filter paper. The filtered extract solutions was then used for phosphorous and potassium analyses. Flame photometer part was used for measuring the potassium concentration of the soil samples while standard solutions were used to determine phosphorous concentration in the soil samples.

4.2.4.3 Quantification of nutrient balances

The NUTMON tool box was used in quantifying Nitrogen, Phosphorous, Potassium flows and balances. Since the study sought to determine the nutrient balances at crop activity level, the approach was adjusted to enable generation of output within an experimental area. The replicates involving intercropping arrangements were the equivalent of the farm section units and the primary production units were the plots comprising of the 25 treatments. Nutrient flows into primary production units were identified as inorganic fertilizer and farm yard manure (IN 1 – inorganic fertilizers, IN 2 – farm yard manure), atmospheric deposition (IN 3) and biological nitrogen fixation (IN 4) and returned plant residue (OUT 2). Nutrient output flows were identified as crop harvest (OUT 1), leaching (OUT 3), volatilization (OUT 4) and soil erosion (OUT5). Flows and balances of nitrogen, phosphorous and potassium were calculated at the end of the experimental period through autonomous assessment of the inputs and outputs (Table 4.1).

Table4.1: Nutrient flows in NUTMON

IN flows	**OUT flows**	**Internal flows**
IN1 Inorganic fertilizers	OUT1 Harvested products	FL1 Feeds
IN2a Organic inputs: purchased manure and feeds	OUT2 Crop residues and manure	FL2 Household waste
IN2b Organic inputs: manure from grazing outside the farm	OUT3 Leaching	FL3 Crop residues
IN3 Atmospheric deposition	OUT4 Gaseous losses	FL4 Grazing of vegetation
IN4 N-fixation	OUT5 Erosion	FL5 Animal manure
IN5 Sedimentation	OUT6 Human excreta	FL6 Farm products to household

Source: De Jager*et al.* (1998)

Hence, nutrient flow for N, P and K were given by (IN1, IN2, OUT1 and OUT2) and use of transfer functions (IN3, IN4 and IN5, and OUT3, OUT4, OUT5 and OUT6) (Van den Bosch et al. 1998) while the nutrient balances were calculated using the equation based on a set of inflows and outflows:

$$\text{Net soil nutrient balance} = \Sigma \text{ nutrient inputs} - \Sigma \text{ nutrient outputs}$$

4.3 Statistical analyses

Data was subjected to analysis of variance (ANOVA) using GENSTAT version 15. (Payne et al. 2011) and means were separated using Fisher's protected LSD at 5% to identify differences between treatments.

4.4 Results and discussion

4.4.1 Initial soil and manure nutrient content

The soil analysis before planting of African nightshade showed that the soil was low in nitrogen, phosphorous and potassium content while the soil pH was moderately acidic (Table 4.2).

Table4.2: Soil and manure chemical properties before planting of African nightshade in KALRO Kisii

Element	Soil	Manure
pH (H_2O)	5.61	8.71
Organic Carbon (%)	2.7	24.5
Nitrogen (%)	0.35	0.7
Phosphorus (ppm)	12	441
Potassium (cmolkg^{-1})	4	25.5

The results for manure showed that nitrogen, phosphorous, potassium and organic carbon levels were sufficient to boost vegetable production while the pH was moderately alkaline. Soil nitrogen, phosphorous and potassium were below the recommended levels while the pH was between the recommended ranges of 5.3-6.1 for vegetable production (Warncke et al. 2004). This implies that for a farmer to exhibit high yields the soil must be supplemented with nutrients from external sources. Hence, because of these nutrient deficits, intervention of farm yard manure which was sufficient in nitrogen, phosphorous and potassium levels will be critical in vegetable production ,however with its moderate alkalinity it will suit best in acidic soils.

4.4.2 Available nitrogen

The results showed that intercropping arrangements and fertilizer combinations had a significant (P=0.05) effect on soil nitrogen levels (Table 4.3).

Table4.3: Influence of combined fertilizer application and spider plant integration in African nightshade cropping system on nitrogen status (Spider plant: ANS row ratios)

Intercropping arrangements	Fertilizer combinations	%N levels
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	0.34
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	0.33
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	0.43
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	0.38
sole ANS	60kg N ha^{-1} farm yard manure	0.45
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	0.33
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	0.33
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	0.44
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	0.44
1:14	60kg N ha^{-1} farm yard manure	0.46
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	0.3
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	0.31
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	0.4
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	0.42
1:2	60kg N ha^{-1} farm yard manure	0.42
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	0.33
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	0.32
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	0.44
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	0.44
1:3	60kg N ha^{-1} farm yard manure	0.45
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	0.34
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	0.31
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	0.43
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	0.44
1:4	60kg N ha^{-1} farm yard manure	0.44
LSD 0.05		0.02
CV		1.1

Soil nitrogen from plots containing sole African nightshade, 1:14 and 1:3 intercrop ratios supplied with FYM (60 kg N ha^{-1}+ 36kg P ha^{-1}) recorded 0.46%N that was higher compared to the initial (0.35%) but this was not significantly different from African nightshade grown at intercrop ratios of 1:14 and 1:3 supplied with urea (30 kg N ha^{-1})+ tri-superphosphate (20 kg P ha^{-1})+FYM (30 kg N ha^{-1}+ 18kg P ha^{-1})and urea (20 kg N ha^{-1})+ tri-superphosphate (10 kg P ha^{-1})+FYM (40 kg N ha^{-1}+ 27kg P ha^{-1}) that resulted in 0.44%N (Table 4.3) In addition, African nightshade at an intercrop ratio of 1:2 supplied with either urea (40 kg N ha^{-1})+ tri-superphosphate (30 kg P ha^{-1})+FYM (20 kg N ha^{-1}+ 9kg P ha^{-1})or urea (60 kg N ha^{-1})+ TSP (40 kg P ha^{-1}) and 1 :4 intercrop ratio supplied with urea (40 kg N ha^{-1})+ tri-superphosphate (30 kg P ha^{-1})+FYM (20 kg N ha^{-1}+ 9kg P ha^{-1})resulted in 0.3%N (Table 4.3).

Combined use of farm yard manure and inorganic fertilizer especially at high ratios of farm yard manure increased nitrogen levels in the soil than pure inorganic fertilizer. This could be attributed to the slow release nature of nitrogen present in farm yard than inorganic fertilizers, which accounts greater soil nitrogen content after harvest. These results agrees with the findings of Zhao et al. (2009) who reported that farm yard manure combined with inorganic fertilizer results in higher increase in soil total nitrogen. Combining farm yard manure with inorganic fertilizer increase synchrony and reduce losses by converting inorganic nitrogen into organic forms. Increase in total nitrogen might be due to the direct addition of nitrogen through farm yard manure to the soil because the low recovery efficiency of nitrogen is associated with its loss by leaching, deni-trification, volatilization and soil erosion (Aspasia et al. 2010).

Plots with 1:2 intercrop ratios recorded total nitrogen content 0.3%N compared to sole African nightshade, 1:14, 1:3 and 1:4. This could be attributed to high competition for nitrogen uptake from both spider plant and African nightshade. Both vegetables are classified as leafy vegetables hence heavy feeders of nitrogen. These results agrees with findings of Choudhuri et al. (2012) working on mustard and potato, reported that less soil nitrogen content is obtained from 1:1 row ratio of mustard and potato compared to sole mustard. Similarly, Verma et al. (2013) reported that geranium and potato intercrop significantly reduces soil nitrogen content compared to geranium mono crop.

4.4.3 Available phosphorous

The results showed that intercropping arrangements and fertilizer application had a significant (P=0.05) effect on soil phosphorous content (Table 4.4). Plots containing sole African nightshade supplied with urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) and sole African nightshade, 1:14 and 1:4 intercrop ratios supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in 14.3ppm P that was higher compared to initial 12.1ppm P, however this was not statistically different from those obtained from plots containing 1:4 intercrop ratios supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) that resulted in 14ppm (Table 4.4).Besides, African nightshade at an intercrop ratio of 1:2 supplied with urea (60 kg N ha^{-1})+ TSP (40 kg P ha^{-1}) resulted in 11.7ppm P, however this was not statistically different from those obtained when the same intercrop arrangement was supplied with urea (40 kg N ha^{-1})+ tri-superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) that resulted in 11.9ppm (Table 4.4).

Table4.4: Influence of combined fertilizer application and spider plant integration in African nightshade cropping system on Phosphorous status (Spider plant: ANS row ratios)

Intercropping arrangements	Fertilizer combinations	P levels (ppm)
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	12.1
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	12.3
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	13.5
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	14.3
sole ANS	60kg N ha^{-1} farm yard manure	14.2
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	12.1
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	12.2
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	13.2
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	14.1
1:14	60kg N ha^{-1} farm yard manure	14.2
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	11.7
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	11.9
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	12.5
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	12.9
1:2	60kg N ha^{-1} farm yard manure	13
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	12
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	12
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	13.1
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	13.6
1:3	60kg N ha^{-1} farm yard manure	13.9
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	12.1
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	12.3
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	13.6
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	13.9
1:4	60kg N ha^{-1} farm yard manure	14
LSD 0.05		0.24
CV		4.7

The total phosphorous content increased in all treatments compared to initial levels. The results also indicated that integration of farm yard manure and inorganic fertilizer nutrient sources had higher amounts of phosphorus in soil than sole application of inorganic fertilizers. The plausible reason to why available soil phosphorous was higher in plots containing urea (20 kg N ha^{-1}) + triple superphosphate (10 kg P ha^{-1}) +FYM (40 kg N ha^{-1} + 27 kg P ha^{-1}) combinations could be attributed to inorganic (Urea) fertilizer that accelerated mineralization and increased the slow release of phosphorous from farm yard manure by stimulating the soil biological activities. The results are in agreement with the findings of Aspasia et al. (2010) who reported that combined organic and inorganic fertilization ameliorates available phosphorous in the soil hence sustaining soil health. Similarly, Indrani et al. (2008) reported that increase of available phosphorus could be attributed to the decomposition of organic matter coupled with release of appreciable quantities of carbon (iv) oxide, which plays an important role in increasing phosphorous availability.

Intercrop ratio of 1:2 recorded the lowest phosphorous levels across fertilizer combinations compared to sole African nightshade, 1:3, 1:4 and 1:14 intercrop ratios. These results could be attributed to more competition for available phosphorous that led to low phosphorous residuals in plots of 1:2. These results conforms with the findings of Choudhuri et al. (2012) who reported that a 2:1 intercrop ratio of mustard and potato resulted in the lowest soil phosphorous levels after harvest. Similarly, Jat et al. (2003) working on ground nuts reported that pigeon pea and ground nut intercrops results into significantly low soil phosphorous levels compared to pigeon pea mono crop.

4.4.4 Available potassium

The results indicated that combined fertilizer application and intercropping arrangements differed significantly (P=0.05) on soil potassium content (Table 4.5). Sole African nightshade supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in 8 cmol K kg^{-1} compared to initial 4 cmol K kg^{-1}, but this was not significantly different from intercrop ratios of 1:4, 1:3 and 1:14 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) that resulted in 7.8 cmol K kg^{-1} (Table 4.5). This was followed by sole African nightshade and 1:3 intercrop ratio supplied with urea (20 kg

N ha^{-1}) + triple superphosphate (10 kg P ha^{-1}) +FYM (40 kg N ha^{-1} + 27 kg P ha^{-1}) that resulted in 7.5 cmol K kg^{-1} (Table 4.5).

Table4.5: Influence of combined fertilizer application and spider plant integration in African nightshade cropping system on Potassium status (Ratios are Spider plant: ANS rows)

Intercropping arrangements	Fertilizer combinations	K levels (cmol kg^{-1})
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	4.11
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	4.12
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	7.1
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	7.5
sole ANS	60kg N ha^{-1} farm yard manure	8
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	4.1
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	4.1
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	7
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	7.4
1:14	60kg N ha^{-1} farm yard manure	7.7
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	3.5
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	3.7
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	5.7
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	6.9
1:2	60kg N ha^{-1} farm yard manure	7
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	4
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	4.1
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	6.9
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	7.3
1:3	60kg N ha^{-1} farm yard manure	7.7
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	4.13
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	4.2
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	7
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	7.3
1:4	60kg N ha^{-1} farm yard manure	7.8
LSD 0.05		0.47
CV		5.2

Further, African nightshade grown at a ratio of 1:2 recorded 3.5cmol K kg^{-1} which was lower compared to initial value of 4 cmol K kg^{-1}, however this was not statistically different from the same intercropping arrangement supplied with urea (40 kg N ha^{-1}) + tri-superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) that resulted in 3.7 cmol kg^{-1} (Table 4.5).

Higher soil potassium content was obtained from plots with high farm yard manure ratios compared to sole inorganic fertilizers (urea and TSP). This could be attributed to increased soil potassium content mineralized from farm yard manure at latter period. Consequently, urea and triple superphosphate fertilizers do not supply potassium which could be the reason for low soil potassium content. Seyed et al. (1998) reported that increased organic carbon facilitates solubilization of different organic nitrogenous compounds into simple and available form, acidifying action of farm yard manure on applied K at the time of decomposition making more potassium available, and reduction of potassium fixation. These results conforms with the findings of Gebrtsadkan et al. (2015) who reported that organic manure elevates soil chemical properties at a higher frequency compared to inorganic fertilizers. However, potassium levels declined in inorganic fertilizer treatments compared to treatments with farm yard manure. This could be attributed to nutrient losses through volatilization, leaching and soil erosion pathways.

Sole African nightshade, 1:14, 1:3 and 1:4 intercrop ratios recorded significantly higher soil potassium content compared to 1:2 intercrop ratios. However there were no significant differences among sole African nightshade, 1:3, 1:4 and 1:14 intercrop ratios. These findings could be attributed to lesser competition ratio values between the African nightshade and spider plant, longer roots and more root volume which facilitated heavy potassium uptake from the soil.

4.4.5 Organic carbon

The results showed that intercropping arrangements and fertilizer application had significant (P= 0.05) effect on soil organic carbon (Table 4.6).

Table4.6: Influence of combined fertilizer application and spider plant integration in African nightshade on Organic carbon status (Ratios are Spider plant: ANS rows)

intercrop arrangement	fertilizer combinations	%C Levels
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	2.75
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	2.78
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	2.86
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	2.87
sole ANS	60kg N ha^{-1} farm yard manure	2.95
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	2.73
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	2.78
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	2.85
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	2.85
1:14	60kg N ha^{-1} farm yard manure	2.95
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	2.72
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	2.73
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	2.76
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	2.79
1:2	60kg N ha^{-1} farm yard manure	2.8
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	2.73
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	2.77
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	2.83
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	2.84
1:3	60kg N ha^{-1} farm yard manure	2.96
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	2.74
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	2.75
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	2.85
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	2.85
1:4	60kg N ha^{-1} farm yard manure	2.94
LSD 0.05		0.022
CV		1.1

Organic carbon content obtained from1:3 intercrop ratios supplied with pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in 2.96% C compared to initial 2.7% C but this was not significantly different from sole African nightshade, 1:14 and 1:4 intercrop ratios when same fertilizer combinations were used that resulted in 2.94% C (Table 4.6). This was followed by % C from sole African nightshade supplied with urea (20 kg N ha^{-1})+ tri-superphosphate (10 kg P ha^{-1})+ FYM (40 kg N ha^{-1}+ 27 kg P ha^{-1})and urea (30 kg N ha^{-1})+ tri-superphosphate (20 kg P ha^{-1})+

FYM (30 kg N ha^{-1}+ 18 kg P ha^{-1}) that resulted in 2.87% C, however they were not statistically different from 1:14 and 1:4 intercrop ratios that resulted in 2.85% C (Table 4.6). In addition, African nightshade grown at a ratio of 1:2 supplied with urea (60 kg N ha^{-1}) + TSP (40 kg P ha^{-1}) recorded 2.72% C, however this was not statistically different from 1:4 and 1:3 intercrop ratios supplied with urea (60 kg N ha^{-1}) + TSP (40 kg P ha^{-1}) that resulted in 2.74% C (Table 4.6).

Sole farm yard manure and combined treatments had significantly higher amount of organic carbon as compared to sole inorganic fertilizer treatments. This could be attributed to high amounts of organic carbon mineralized from farm yard manure. Similar results have been reported by Abay et al. (2011) who found that farm yard manure decomposition increases the amount of organic matter in the soil. Similarly, Gebrtsadkan et al. (2015) reported that combined fertilizer application with high farm yard manure rates results in higher amounts of soil organic carbon compared to sole inorganic fertilizer. Further, Shirani et al. (2002) reported a three-fold increase in soil organic carbon levels with an application of farm yard manure.

1:3 intercrop ratio supplied with farm yard manure recorded the highest organic carbon levels followed by 1:14 intercrop ratios. These results could be attributed to higher quantities of litter fall and root necromass incorporated in soil during the growing period from spider plant and African nightshade. Moreover, both vegetables could produce numerous roots which could remain in soil as a source of carbon after decomposition. These results agrees with the findings of Xiao et al. (2013) working on cucumber reported that garlic and cucumber intercrops results in higher soil organic carbon compared to cucumber mono-crop. Similarly, the increased soil organic carbon from the 1:3 and 1:4 could be ascribed to root exudates from both crops that enhance soil enzyme activities which play a crucial role in the decomposition of organic residues and organic carbon recycling in the soil.

4.4.6 Soil pH

The results showed that soil pH values were significantly (P=0.05) affected by intercropping arrangements and fertilizer combinations (Table 4.7).

Table4.7: Influence of combined fertilizer application and spider plant integration in African nightshade on the pH status (Ratios are Spider plant: ANS rows)

Intercropping arrangements	Fertilizer combinations	pH level
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	5.58
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	5.63
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	5.69
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	5.76
sole ANS	60kg N ha^{-1} farm yard manure	6.27
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	5.57
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	5.61
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	5.68
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	5.75
1:14	60kg N ha^{-1} farm yard manure	6.24
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	5.55
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	5.62
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	5.67
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	5.75
1:2	60kg N ha^{-1} farm yard manure	6
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	5.58
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	5.62
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	5.69
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	5.76
1:3	60kg N ha^{-1} farm yard manure	6.2
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	5.58
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	5.62
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	5.7
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	5.8
1:4	60kg N ha^{-1} farm yard manure	6.3
LSD 0.05		0.076
CV		2.2

African nightshade grown at a ratio of 1:4 supplied with pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in pH value of 6.31 compared to initial levels of 5.61 but this was not significantly different from sole African nightshade and 1:14 intercrop ratio supplied with pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) that resulted in 6.27 and 6.24 respectively (Table 4.7). However, this was followed by 1:2 intercrop ratio supplied with pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) that resulted in 6.0 pH values and 1:4 intercrop ratio supplied with urea (20 kg N ha^{-1}) + tri-superphosphate (10 kg P ha^{-1})+ FYM (40 kg N ha^{-1}+ 27 kg P ha^{-1})that recorded 5.8 pH values (Table 4.7). Besides, African nightshade grown at a ratio of 1:2 supplied with urea (60 kg N ha^{-1}) + TSP (40 kg P ha^{-1}) exhibited a decline of pH value (5.55) compared to initial pH value (5.61) but this was not statistically different from sole African nightshade, 1:4 1:3 and 1:14 supplied with urea (60 kg N ha^{-1}) + TSP (40 kg P ha^{-1}) that resulted in 5.58 (Table 4.7).

Farm yard manure and inorganic fertilizers provide multiple benefits for improving soil chemical and physical properties (Basso and Ritchie, 2005). In this study, treatments with high rates of farm yard manure obtained high pH values compared to those with pure inorganic fertilizers These results corroborates with Gebrtsadkan et al. (2015) who reported that integration of inorganic fertilizers with farm yard manure increases the soil pH. Similarly, Citak et al. (2010) found that use of farm yard manure increases soil pH while inorganic fertilizer results into a decrease in soil pH values. Further, it could be also attributed to increased amount of nitrogen and organic carbon which facilitates microbial biomass and their activities consequently increasing the soil pH.

4.4.7 Nitrogen balances

Results indicated that intercropping arrangements and fertilizer combinations had a significant (P=0.05) effect on soil nitrogen balances (Table 4.8).

Table4.8: Nitrogen balances (kg ha^{-1} yr^{-1}) as affected by intercropping arrangements and fertilizer combinations (Ratios are Spider plant: ANS rows)

Intercropping arrangements	Fertilizer combinations	N balance (kg ha^{-1} yr^{-1})
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-33.2
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-33.1
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-20.2
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-18.7
sole ANS	60kg N ha^{-1} farm yard manure	-9
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-34.1
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-26.6
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-21.6
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-21.2
1:14	60kg N ha^{-1} farm yard manure	-9.7
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-33.4
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-26.5
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-24
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-21.6
1:2	60kg N ha^{-1} farm yard manure	-9.7
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-35
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-21.1
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-25
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-13.4
1:3	60kg N ha^{-1} farm yard manure	-10.2
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-34.7
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-26.8
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-23.8
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-24.3
1:4	60kg N ha^{-1} farm yard manure	-13.7
LSD 0.05		10.5
CV		17.4

Negative N balances were obtained across intercropping arrangements. Sole African nightshade supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded nitrogen losses of 9 kg ha^{-1} yr^{-1} but this was not significantly different from African nightshade grown at intercrop ratios of 1:14, 1:2, 1:3 and 1:4 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) that resulted in 9.7 kg ha^{-1} yr^{-1}, 9.7 kg ha^{-1} yr^{-1}, 10.2 kg ha^{-1}yr^{-1} and 13.2 kg ha^{-1} yr^{-1} respectively (Table 4.8). In addition,1:3 intercrop ratio supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) recorded more negative N balances (more nitrogen losses) of -35 kg ha^{-1} yr^{-1}, however this was not significantly different from an application of urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) and urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}) across intercropping arrangements (Table 4.8).

Negative nitrogen balances across treatments could be attributed to nutrient removal of harvested product of both African nightshade and spider plant. Removal of above ground biomass through harvesting had adverse effects on nitrogen balances in the soil (Fatima et al. 2008). The losses could also be attributed to other processes such as leaching, soil erosion and nitrogen immobilization. An intercrop ratio of 1:2 recorded the highest nitrogen losses as compared to sole African nightshade. This also could be attributed to high competition for soil nitrogen for both spider plant and African nightshade due to intra and inter-specific competition. These results agrees with those of Kroeze et al. (2003) who reported that negative nitrogen balances are caused by high outflow of nitrogen through harvested products, crop residues, volatilization and leaching.

Less negative balances noted in sole African nightshade could be attributed to the vegetable's inability to fix nitrogen from the soil. Sole African nightshade with only farm yard manure recorded the lowest negative nitrogen balances compared to other treatments which could be attributed to low mineralization of farm yard manure. These results agrees with those of Turne et al. (2007) who reported that nutrients from organic fertilizer can be held by microbial biomass but the organisms also play an important role in nutrient losses. Further, Patterson et al. (2007) found that chemical fertilizers provides quick results but in long-run contributes to soil corrosion, environmental pollution and health hazards. Less negative nitrogen balances were noted in treatments where farm yard manure was incorporated, with pure farm yard manure recording the lowest negative nitrogen balances. These results could be attributed to slow release of nitrogen and increase of soil stability. Furthermore, combined use of farm yard manure and chemical fertilizers will narrow down the negative nitrogen balances considerably, moreover improving soil fertility in many cropping systems.

4.4.8 Phosphorous balances

The results showed that there was a significant (P=0.05) effect for intercropping arrangements and fertilizer combination on soil phosphorous balances (Table 4.9). Application of pure farm yard manure and urea (20 kg N ha^{-1}) + triple superphosphate (10 kg P ha^{-1}) + FYM (40 kg N ha^{-1} + 27 kg P ha^{-1})had significantly less negative balances compared to other treatments across intercropping arrangements (Table 4.9). Sole African nightshade supplied with pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded negative phosphorous balances of 9.9 kg ha^{-1} yr^{-1} but this was not significantly different from an application of FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) and urea (20 kg N ha^{-1}) + triple superphosphate (10 kg P ha^{-1}) + FYM (40 kg N ha^{-1} + 27 kg P ha^{-1}) across intercropping arrangements (Table 4.9). African nightshade grown at an intercrop ratio of 1:2 supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) recorded the highest phosphorous losses of -25.2 kg ha^{-1} yr^{-1} however this was not statistically different from 1:14, 1:3 and 1:4 supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) that resulted in 21.2 kg ha^{-1} yr^{-1}, 20.2 kg ha^{-1} yr^{-1} and 20 kg ha^{-1} yr^{-1} respectively (Table 4.9).

Table4.9: Phosphorous balances (kg ha^{-1} yr^{-1}) as affected by intercropping arrangement and fertilizer combinations (Ratios are Spider plant: ANS rows)

Intercropping arrangements	Fertilizer combinations	P balance (kg ha^{-1} yr^{-1})
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-18.5
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-17.7
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-13.4
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-10.5
sole ANS	60kg N ha^{-1} farm yard manure	-9.9
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-21.2
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-20.1
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-20.4
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-10.8
1:14	60kg N ha^{-1} farm yard manure	-10.2
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-25.2
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-17.2
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-17.1
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-10.8
1:2	60kg N ha^{-1} farm yard manure	-10.7
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-20.1
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-17.5
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-15.6
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-11.4
1:3	60kg N ha^{-1} farm yard manure	-10.3
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-20
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-19.1
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-15.1
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-12.4
1:4	60kg N ha^{-1} farm yard manure	-10.4
LSD 0.05	(Fertilizer combinations)	6.1
CV		14.9

Negative phosphorous balances exhibited in all treatments could be attributed to phosphorous uptake by both African nightshade and spider plant which was removed through the harvested products. These results concur with those of Wang et al. (2008) who reported that vegetable are heavy feeders of phosphorous. Further, Nuruzzaman et al. (2005) recorded that the companion crops when intercropped increase phosphorous uptake from the soil through nutrient mobilization. More negative balances were noted in the intercrop ratio of 1:2 which could be attributed to higher uptake by both vegetables. Lambers et al. (2006) reported that plant roots release large amounts of organic acids to mobilize nutrients when bound to soil particles that are inaccessible for direct plant uptake. Besides, more negative balances noted in treatments with pure inorganic fertilizer could be attributed to ready availability of phosphorous for plant uptake, leaching and gaseous losses. Farm yard manure takes a longer period to release phosphorous through mineralization although the microbial biomass also facilitates nutrient losses (Turne et al. 2007). Organic fertilizers ameliorates soil properties and supply nutrients throughout the growing period (Sharma et al. 2012) which could be the reason why less negative phosphorous balances were exhibited in treatments with farm yard manure.

4.2.9 Potassium balances

The results showed that there was a significant (P=0.05) effect for fertilizer combinations and intercropping arrangements on soil potassium balances (Table 4.10). More negative potassium balances (33.9 kg ha^{-1} yr^{-1})were recorded when African nightshade was grown at an intercrop ratio of 1:2 supplied with urea (60 kg N ha^{-1})+ triple superphosphate (40 kg P ha^{-1}), however this was not statistically different from 1:4and 1:3 supplied with urea (60 kg N ha^{-1})+ triple superphosphate (40 kg P ha^{-1}) that resulted in 33.2 kg ha^{-1} $yr^{-1}$and 32.9 kg ha^{-1} yr^{-1} respectively (Table 4.10).This was followed by African nightshade grown at an intercrop ratios of 1:4 and 1:3 supplied with urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1})+ FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1})that resulted in 30 kg ha^{-1} $yr^{-1}$and 31.6 kg ha^{-1} yr^{-1} respectively (Table 4.10).Further, less potassium losses were obtained with the application of FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) across intercropping arrangements.

Table4.10: Potassium balances (kg ha^{-1} yr^{-1}) as affected by intercropping arrangement and fertilizer combinations

Intercropping arrangements	Fertilizer treatments	K balance (kg ha^{-1} yr^{-1})
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-21.1
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-19.2
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-14.1
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-10.4
sole ANS	60kg N ha^{-1} farm yard manure	-5.9
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-22.5
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-23.5
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-24.6
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-13.4
1:14	60kg N ha^{-1} farm yard manure	-6.9
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-33.9
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-27.3
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-22.6
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-13.2
1:2	60kg N ha^{-1} farm yard manure	-11
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-32.9
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-30
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-19.7
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-18.1
1:3	60kg N ha^{-1} farm yard manure	-7.1
	60kg N ha^{-1} urea + 40kg P ha^{-1} TSP	-33.2
	40kg N ha^{-1} urea + 30kg P ha^{-1} TSP +20kg N ha^{-1} FYM	-31.6
	30kg N ha^{-1} urea + 20kg P ha^{-1} TSP +30kg N ha^{-1} FYM	-17.1
	20kg N ha^{-1} urea + 10kg P ha^{-1} TSP +40kg N ha^{-1} FYM	-14.1
1:4	60kg N ha^{-1} farm yard manure	-7.3
LSD 0.05		6.5
CV		21.0

African nightshade grown as a mono crop recorded the lowest negative potassium balances of -5.9 kg ha^{-1} yr^{-1}but this was not significantly different from 1:2, 1:4, 1:3 and 1:14 intercrop ratios supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) that recorded -11 kg ha^{-1} yr^{-1}, -7.3 kg ha^{-1} yr^{-1}, -7.1kg ha^{-1} yr^{-1} and -6.9 kg ha^{-1} yr^{-1} respectively (Table 4.10). However Potassium balances were not significantly different for 1:4 and 1:3 intercropping arrangements across fertilizer combinations (Table 4.10).

There were negative potassium balances across treatments. These results could be attributed to removal of potassium nutrient through harvested African nightshade and spider plant. Phong et al. (2011) while conducting studies on vegetables noted that negative potassium balances were found in vegetable fields. More negative potassium losses were noted in the intercrop ratio of 1:2 which could be attributed to nutrient competition hence increased exploitation of the resource base. These findings agrees with those of Verma et al. (2007) working on various vegetable cropping systems reported that all cropping systems resulted into negative potassium balances. Less negative potassium balances were noted in a sole African nightshade treatment compared to other intercrops. This could be attributed to the vegetable's inability to fix and utilize available potassium. Further, during the harvestable period the vegetable could not enter into reproductive period leading to seed formation which could facilitate more potassium uptake.

The lowest negative potassium balances were experienced in the sole African nightshade with only farm yard manure. This could be attributed to slow mineralization of potassium from farm yard manure hence unavailable for plant uptake during its growth. These results agrees with those of Sharma et al. (2012) who reported that organic manure treatments had high potassium content compared to inorganic fertilizers. Further, potassium losses through leaching and gaseous emissions were minimal in farm yard manure treatments (Goulding et al. 2008). Besides, Dou et al. (2016) reported that organic manure after some years leads to an increase in the organic carbon, soluble phosphorus, exchangeable potassium, pH and also the reserve pool of stored nutrients and maintain relativity stable EC level. In the second season, the negative potassium balances were lower in treatments with farm yard manure compared to the first season which could be attributed to slow mineralization and release of farm yard manure throughout the growing period. Srinivasarao et al. (2010) noted that continuous cropping with fertilization in the form of farm yard manure to vegetable crops results in enrichment of various K forms in soil.

4.5 Conclusion

The spider plant- African nightshade intercropping arrangements and fertilizer combination influenced soil nutrient status and balances. Application of pure urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) combined with intercrop ratio of 1:2 exhibited low soil N, P K,C and pH levels compared to compared to initial soil nutrient levels while application of pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in higher nutrient levels across all intercropping arrangements. Further, Sole African nightshade supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded negative nutrient balances of -9 kg N, -9.9 kg P and -5.4 kg K ha^{-1} yr^{-1}however, an intercrop ratio of 1:2 (Spider plant: ANS) combined with urea (60 kg N ha^{-1})+ triple superphosphate (40 kg P ha^{-1}) recorded higher negative nutrient balances of -36.5 N, -25.2 P and -34.2 kg K ha^{-1} yr^{-1}.

CHAPTER FIVE

ECONOMIC FEASIBILITY OF AFRICAN NIGHTSHADE AS INFLUENCED BY INTERCROPPING ARRANGEMENTS AND COMBINED FERTILIZER APPLICATIONS

Abstract

Small farmers involved in African nightshade production are not realizing high returns as expected because of low soil fertility and non-sustainable intercropping systems. This study was therefore conducted with the objective of evaluating the economic feasibility of different intercropping arrangements with combined use of farm yard manure and inorganic fertilizers in African nightshade production. The study was carried out at Kenya Agricultural and Livestock Research Organization, Kisii County. The experiments were laid out in a complete randomized block design with a split plot arrangement replicated three times. The main plots were intercropping arrangements of spider plant: African nightshade rows and sub plots had fertilizer combinations of Farm yard manure (FYM), urea and triple super phosphate (TSP). Data on total fresh leaf yield for both vegetables was measured and used for gross margin analysis. Intercrop ratio of 1:4 supplied with urea (60kg N ha^{-1}) + triple superphosphate (40kg P ha^{-1}) resulted in a combined yield of 37,500 kg ha^{-}1 with higher gross margins of KES 294,243 compared to Sole African nightshade supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) that recorded fresh leaf yield of 35100 kg ha^{-1} with gross margins of KES 276,091. Intercrop ratio of 1:2 supplied with pure FYM(60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest combined yields of 10,700 kg ha^{-1} with gross margins of KES 37,354. Therefore,farmers can grow African nightshade with spider plant at an intercrop ratio of 1:4 supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) to maximize on gross margin but for farmers who opt to grow African nightshade as a mono crop then application of only inorganic fertilizer will be used. However, for those farmers who cannot afford inorganic fertilizers, can grow African nightshade at an intercrop ratio of 1:2 supplied with FYM (60 kg N ha^{-1}; 36 kg P ha^{-1}) since it is also profitable.

Keywords: African nightshade, intercropping, fertilizer application, Gross margin analysis.

5.1 Introduction

The economy of many tropical countries is based on agricultural production (Lithourgidis *et al.*, 2011). Increasing population in these countries leads to reduced agricultural land and increased demand for agricultural products. One of the remedies to increase agricultural production in small and marginal units of farming is to increase the productivity per unit time and area (Hauggaard-Nielsen and Jensen, 2001). Vegetable crops occupy an important role in diversification of agriculture and has played pivotal role in food security of ever burgeoning population (Godfray et al. 2010). Hence a cropping system that can increase the rate of vegetable production and lower the cost of production will provide economic opportunity for farmers. Intercropping has been identified as a promising sustainable system that makes effective use of available resources (Thayamini & Brintha, 2010) i.e soil nutrients that will result in reduced cost of production. It has also gained wide acceptability among farmers of developing countries because of its economic advantages resulting from combined yields compared to mono crops (Lithourgidis et al. 2011). Since, excessive use of inorganic fertilizers contribute to environmental damage such as nitrate pollution; vegetables grown in intercropping are barely regarded as an alternative and sustainable way of utilizing soil nutrients supplied from inorganic and organic fertilizers (Fustec et al. 2010). The main effect of intercropping vegetables is because of more efficient utilization of available resources and increased productivity compared with sole crop (Mao et al. 2012). Intercropping provides high assurance against crop failure, especially in areas subject to extreme weather conditions and provides greater financial stability for farmers, making the system more suitable particularly for labor-intensive small farms. Farmers can reduce the risk for total vegetable failure by growing more than one vegetable crop in their fields (Alhaji et al. 2008). Moreover, intercropping may result in increased yield of main or companion or both crops as compared to sole cropping. However, it may result in reduced yield of one (Egbe and Bar, 2010) or both crops (Ghosh et al. 2006). However, in intercropping systems, not the yield but economic return is more important due to net benefit to the growers.

African nightshade is highly nutritious and has medicinal value since they are both nutritive and therapeutic (Abukutsa-Onyango, 2003). According to Adobooye et al. (2004), the vegetable can be used to eliminate malnutrition and promote healthy diets through its increased sustainable production and consumption. Moreover, spider plant is also a nutritious indigenous vegetable with medicinal value (Narendhirakannan et al. 2005). Apart from these benefits, spider plant has been also observed to have insecticidal, anti-feedant and pest repellant properties hence intercropping African nightshade with spider plant will result into a combined yield advantage and reduce synthetic pesticide application.

Vegetable production with little or no fertilizer application has been associated with a decline in soil fertility which subsequently reduces yields. Degradation is brought by loss of organic matter which consequently results in soil acidity, nutrient imbalance and finally low crop yields. However, the access and use of inorganic fertilizers alone is expensive to small scale farmers and may cause problems for human health and environment (Ayoola and Makinde, 2007).Farm yard manure can serve as alternative practice to against use of inorganic fertilizers as they aid in improving soil structure, increase soil organic carbon provide significant quantities of major and micro nutrients, and have a persistent effect on the soil over years (Suresh et al. 2004).

The current study was therefore, undertaken to investigate feasibility of producing African nightshade intercropped with spider plant combined with fertilizer application to maximize productivity and returns per unit area

5.2 Materials and methods

5.2.1 Site description

The study was conducted at KALRO, Kisii County, Kenya between February 2015 and February 2016. Kisii County lies between Longitudes: 34° 46' E and Latitudes: 0° 41' S. It receives a bimodal type of rainfall with both long and short rain season having a mean of 1500mm p.a. The long rains are received between March and June with a mean of 790mm and the short rains are received between September and November with a mean of 500mm. The area experiences maximum temperatures of 30^{o}C and minimum temperatures of 15^{o}C.The soils are well drained nitsols and high amounts of organic matter (Soil handbook of Kenya 2000). Main economic activities of the inhabitants are crop farming, small scale trade, dairy farming, commercial businesses and soapstone carvings.

5.2.2 Experimental design and treatments

The experiment was laid in a randomized complete block design with three replications with a split plot arrangement replicated three times. The main (4.8 by 11m) plots consisted of intercropping arrangements;(i) sole African nightshade, (ii) spider plant surrounding 14 rows of African nightshade (1:14),(iii) one row of spider plant intercropped with 2 rows of African nightshade (1:2), (iv) one row of spider plant intercropped with 3 rows of African nightshade (1:3) and (v) one row of spider plant intercropped with 4 rows of African nightshade (1:4). In the sub plots (4.8 by 1.8m),fertilizer combination were; (i) pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}), (ii) pure inorganic fertilizer- urea (60 kg N ha^{-1}) + TSP (40 kg P ha^{-1}), (iii) urea (30 kg N ha^{-1}) + TSP (20 kg P ha^{-1}) + FYM (30 kg N ha^{-1}+ 18 kg P ha^{-1}), (iv) urea (20 kg N ha^{-1})+ TSP (10 kg P ha^{-1}) + FYM (40 kg N ha^{-1}+ 27 kg P ha^{-1}), (v) urea (40 kg N ha^{-1}) + TSP (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}).At planting urea and tri-superphosphate were banded together while farm yard manure was applied two weeks prior to planting at rates that depended on the treatment for each plot. The plots were ploughed and harrowed before planting using hand hoes. Furrows were made and five seeds of both spider plant and African nightshade (depending on the intercrop arrangement) were sowed directly at a spacing of 30cm x 15cm and thereafter thinning was done to one plants per hole giving a total of 16 rows per plot. Hand weeding was done regularly to ease competition from weeds and the crop solely depended on rainfall.

The vegetables were harvested at maturity and yields calculated for each treatment. This was scaled up to yield in kg ha^{-1}. The yields were converted to 13kg buckets per hectare as they would if being produced for sale by the small-scale farmers and the gross margins computed to determine the most profitable combination(s). Gross margin is a proxy for profitability. It is in turn a reflection of commercial viability of growing African nightshade under different intercropping arrangements and fertilizer combinations.

Calculation of gross margin (GM) was therefore given by:

Gross Margin (GM) = GI – TVC

Where:

GI = Gross income = Yield (kg) x Price per kg; Price per kg for both vegetables = KSh. 10

TVC = Total variable cost (labor, manure/fertilizer, seed and pesticides) as follows:

Labor = KSh 200 per man day

Seed = KSh300 per 200g of seed; 600g of seed per hectare

Cost of fertilizer = KSh 70 per kg; 130.4kg per hectare of Urea; 86.9kg of TSP per hectare

Cost of Manure = KSh 2 per kg; 5.9 tons per hectare

5.2.3 Calculation of Gross margins for production systems that recorded significantly high yields.

Using the different intercropping and fertilizer combinations, the following famer scenarios were used to compare gross margins from the different production systems.

Farmer 1: sole African nightshade supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1})

Farmer 2: Sole African nightshade supplied with urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1})

Farmer 3: Spider plant: African nightshade intercrop ratio of 1:4 supplied with urea (60kg N ha^{-1}) +triple superphosphate (40kg P ha^{-1})

Farmer 4: Spider plant: African nightshade intercrop ratio of 1:4 supplied with urea (40kg N ha^{-1}) + triple superphosphate (30kg P ha^{-1}) + FYM (20kg N ha^{-1}+ 9 kg ha^{-1})

Farmer 5: Spider plant: African nightshade intercrop ratio of 1:2 supplied with pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1})

5.3 Results and discussions

The results indicated that sole African nightshade supplied with fertilizer combination of urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) resulted in African nightshade fresh leaf yield of 35,100 kg ha^{-1} that was not significantly different from that obtained from sole African nightshade supplied with urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) that resulted in fresh leaf yield of 32,500 kg ha^{-1} (Table 5.1).

Table5.1: Combined yields of African nightshade and spider plant for different production systems

Fertilizer combinations	Combined fresh leaf yield for ANS and spider plant (kg ha^{-1} season^{-1}). Intercropping arrangements(spider plant: African nightshade ratio)									
	Sole ANS		1:14		1:2		1:3		1:4	
	ANS	SP	ANS	SP	ANS	SP	ANS	SP	ANS	SP
60kgN/ha urea + 40kgP/ha TSP	35100	0	29300	6000	18200	12700	21800	13700	23800	13700
40kgN/ha urea + 30kgP/ha TSP +20kgN/ha FYM	32500	0	27300	6900	15900	12500	21300	13400	23500	11400
30kgN/ha urea + 20kgP/ha TSP +30kgN/ha FYM	22300	0	17800	2600	11800	5200	15000	5400	16400	5700
20kgN/ha urea + 10kgP/ha TSP +40kgN/ha FYM	19300	0	17300	1800	10010	2390	14000	2500	15900	2500
60kgN/ha farm yard manure	16300	0	15100	1800	8910	1790	12200	2300	9210	2190

African nightshade grown at an intercrop ratio of 1:4 supplied with urea (60kg N ha^{-1})+triple superphosphate (40kg P ha^{-1}) resulted in a combined yields of 37,500 kg ha^{-1}while an intercrop ratio of 1:4 supplied with urea (40kg N ha^{-1}) + triple superphosphate (30kg P ha^{-1}) + FYM (20kg N ha^{-1}+ 9 kg ha^{-1}) obtained combined yields of 34,900 kg ha^{-1} for African nightshade and spider plant (Table 5.1). Intercrop ratio of 1:2 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in combined yields of 10,700 kg ha^{-1} (Table 5.1).

Intercropping is a crop management system involving two or more economic species grown together for at least a portion of their respective productive cycle. However, there is no yield advantage over the mono crops (Sullivan, 2003). In this study, yields across intercropping arrangements were lower compared to sole African nightshade. These results agree with the findings of Kabura et al. (2008) working on pepper and onion intercrops, reported that higher yield values were obtained from sole pepper compared to component crops in intercropping combination. Although yield of component crops in an intercropping combination was reduced, combined yields from the intercrops were higher compared to mono crop African nightshade. This could be attributed to better utilization of available resources, however optimum plant density of individual crops should not be exceeded beyond certain limits to avoid interplant competition Suvilla, (2003) which could be the reason for lower combined yields obtained when African nightshade is grown at an intercrop ratio of 1:2 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}).

5.3.1 Gross margin analysis of the different production systems that resulted in high leaf yields

The gross margins obtained from each production system depended on the inputs and cropping arrangement used by a producer. The different gross margins based on these systems is presented in Table (5.2). Farmer 3 recorded the highest gross margins of KES 294,243 followed by farmer 1 (KES 276,091), farmer 4 (KES 268,839), farmer 2 (KES 251,587) and lastly farmer 5 (37,354) (Table 5.2).

Table5.2: Gross margin analysis for different farmer scenarios

	Farmer 1	**Farmer 2**	**Farmer 3**	**Farmer 4**	**Farmer 5**
Gross income (GI) (KES ha^{-1} season^{-1})	**351,000**	**325,000**	**375,000**	**349,000**	**107,000**
Total variable cost (TVC)(KES ha^{-1} season^{-1})					
African nightshade Seed	900	900	675	675	565
Spider plant seed	0	0	225	225	335
Harrowing	4,135	4,135	4,135	4,135	4,135
Planting	8,267	8,267	10,333	10,333	10,333
Weeding	12,400	12,400	12,400	12,400	12,400
Harvesting	14,468	14,468	20,255	20,255	14,468
Transport	4,500	4,500	4,500	4,500	4,500
Manure	0	3,968	0	3,968	11,900
Fertilizer	15,214	10,650	15,214	10,650	0
Pesticides	8,025	8,025	6,020	6,020	4,010
Land	7,000	7,000	7,000	7,000	7,000
Total	**74,909**	**73,413**	**80,757**	**80,161**	**69,646**
Gross margin (GI-TVC)	**276,091**	**251,587**	**294,243**	**268,839**	**37,354**

Through intercropping, farmers can achieve full production of the main crop and also an additional yield associated with an increased plant population of the second crop component and as a result increase incomes obtained by smallholder farmers (Geno and Geno, 2001). However, the profitability of different production systems is determined by their production costs. Gross margins represent the actual income to the farmer and are used to evaluate economic suitability of any cropping system (Hauggaard-Nielsen and Jensen, 2001).However, development of feasible and economically practical intercropping system mainly depends on the adaptation of planting pattern and selection of compatible vegetable crops. Intercrop ratio of 1:4 supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) obtained higher gross margins compared to those obtained from sole African nightshade supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}). This could be attributed to combined yield advantage of the two vegetables that resulted in higher gross margins compared to sole African nightshade. These results agree with the findings of Seran et al. (2009) working on amaranth and radish intercrop who reported that an intercrop ratio of radish: amaranth (1:4) obtains higher gross margins compared to respective mono crops. Further, production of African nightshade at an intercrop ratio of 1:4 supplied with urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) obtained higher gross margins compared to sole African night shade supplied with the same fertilizer combinations giving a farmer an added advantage for vegetable and income diversification. This could be attributed to better utilization of available resources that enhanced growth of component crops. These results agree with the findings of Mini et al, (2005) working on cow pea and okra intercrops who reported that high gross margins are realized from the intercrops compared to gross margins from component crops. Besides, inter-cropping occupies greater land use efficiency and results in higher economic net return per unit area as compared to mono cropping (Saker et al. 2007). Qasim et al. (2013) working on pea and cauliflower intercrops, reported that intercrops obtains higher gross margins compared to corresponding mono crops. Further, the results could be attributed to maximum utilization of soil nutrients supplied from inorganic and organic fertilizers. Mini et al, (2005) working with pea and okra intercrops reported that intercropping okra with pea obtains the highest gross margins due to better utilization of available soil nutrients. Although African nightshade grown at an intercrop ratio of 1:2 supplied with (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest gross margins compared to all other production systems it will also serve as an economic remedy for those farmers who cannot afford inorganic fertilizers. Gebrtsadkan et al, (2015) working on tomato reported that application of inorganic fertilizer obtains higher gross margins but the use of farm yard manure is also profitable. Similarly, Alam et al, (2004) reported that higher gross margins are obtained when combined inorganic and organic manure are used.

5.4 Conclusion

African nightshade grown at an intercrop ratio of 1:4 supplied with urea (60kg N ha^{-1})+triple superphosphate (40kg P ha^{-1}) obtained the highest gross margins followed by sole African nightshade supplied with the same fertilizer combinations and an intercrop ratio of 1:4 supplied with urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}). An intercrop ratio of 1:2 supplied with (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest gross margins.

CHAPTER SIX

GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Intercropping arrangements and fertilizer application influenced growth and yield of African nightshade, nutrient status and balances and gross margins of different treatments. Fertilizer combinations influenced the number of branches and leaves per plant with application of Urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) recording a high number of branches and leaves per plant that was comparable to when Urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}) was used. Further, highest total fresh leaf yield was produced when sole African nightshade and intercropping of Spider plant and African nightshade at a ratio of 1:14 (spider plant as border rows) supplied with either Urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) or Urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM(20 kg N ha^{-1}+ 9 kg P ha^{-1}) was used in the production of the vegetable while African nightshade grown at an intercrop ratio of 1:2 supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest fresh leaf yield.

On nutrient status and balances, application of urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) combined with intercrop ratio of 1:2 exhibited low soil N, P K, C and pH levels compared to initial soil nutrient levels while application of pure FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in higher nutrient levels across all intercropping arrangements. Further, Sole African nightshade supplied with FYM (60 kg N ha^{-1}+ 36 kg P ha^{-1}) recorded negative nutrient balances of -9 kg N, -9.9 kg P and -5.4 kg K ha^{-1} yr^{-1}however, an intercrop ratio of 1:2 (Spider plant: ANS) combined with urea (60 kg N ha^{-1})+ triple superphosphate (40 kg P ha^{-1}) recorded higher negative nutrient balances of -36.5 N, -25.2 P and -34.2 kg K ha^{-1} yr^{-1}.

Further, African nightshade grown at an intercrop ratio of 1:4 supplied with urea (60kg N ha^{-1})+triple superphosphate (40kg P ha^{-1}) obtained the highest gross margins followed by sole African nightshade supplied with the same fertilizer combinations and an intercrop ratio of 1:4 supplied with urea (40 kg N ha^{-1}) + triple superphosphate (30 kg P ha^{-1}) + FYM (20 kg N ha^{-1}+ 9 kg P ha^{-1}). An intercrop ratio of 1:2 supplied with (60 kg N ha^{-1}+ 36 kg P ha^{-1}) resulted in the lowest gross margins

6.2 Recommendations

It can therefore be recommended that farmers can grow African nightshade with spider plant at an intercrop ratio of 1:4 supplied with urea (60 kg N ha^{-1}) + triple superphosphate (40 kg P ha^{-1}) to maximize on gross margins and increase nutritional diversity but for farmers who opt to grow a mono crop of African nightshade then application of only inorganic fertilizers will be preferable. However, for those farmers who cannot afford inorganic fertilizers, can grow African nightshade at an intercrop ratio of 1:2 supplied with FYM (20 kg N ha^{-1}; 9 kg P ha^{-1}) since it is also profitable and facilitates reduction in soil nutrient losses. Although these technologies will empower small scale farmer economically, more has to be done to realize the most compatible vegetable crops, more particularly with leguminous vegetables that will enhance nutrient use efficiency, reduce production costs and maximize gross margins.

REFERENCES

AbayAyalew, KelsaKena and TesfayDejene, (2011).Application of NP fertilizers for better production of teff on different types of soils in southern Ethiopia; Journal of Natural Science Research, Volume 1(1)Addis Ababa, Ethiopia.

Abukutsa-Onyango MO (2003). Unexploited potential of indigenous African indigenous vegetables in Western Kenya.Maseno Journal of Education, Arts and Science; 4:103-122.

Abukutsa-Onyango MO (2004). Crotalaria brevidensBenth.In: GJH Grubben, & Denton, OA (Eds). Plant Resources of Tropical Africa 2.Vegetables. PROTA Foundation, Wageningen, Netherlands/Backhuys Publishers, Leiden, Netherlands/CTA, Wageningen, Netherlands:229-231.

AbuktusaOnyango, J. C. Onyango, and B. Jama, (2002). Traditional crops in Western Kenya. In Adaptive Technologies for increased Production, Volume 3, IRPS.Maseno University, Kenya, 14-23.

Achieng, J.O., Ouma, G., Odhiambo, G., Muyekho, F. (2010).Effect of farmyard manure and inorganic fertilizers on maize production on Alfisols and Ultisols in Kakamega, western Kenya. Agriculture and Biology Journal of North America 1(4):430-439.

Adani F, Genevini P, Ricca G, Tambone F, Montoneri E (2007). Modification of soil humic matter after 4 years of compost application. Waste Manage 27: 319–324. doi: 10.1016/j.wasman.2006.04.004

Adebooye O. C. and Opabote J. T. (2004). Status of conservation of the indigenous leaf vegetables and fruits of Africa. African Journal of Biotechnology 3, 700-705

Adeniyi, O.R. (2011). Economic aspects of intercropping systems of vegetables (okra, tomato and cowpea). Afr. J. Plant Sci. 5:648-655.

Akanbi, W.B., Togun, A.O., Adediran, J.A., Ilupeju, E.A.O. (2010). Growth, dry matter and fruit yields components of okra under organic and inorganic sources of nutrients. American-Eurasian Journal of Sustainable Agriculture 4(1):1-13.

Akande, OluwatoyinboM.O. F.I, Makinde E.A., Adepoju A.S. and AdepojuI.S.(2010). Response of Okra to organic and inorganic fertilization. Nature and Science 8(11): 261-266.

Alam S.M.,TahirS.A.,Shah and AliS. (2004). Phosphorus management in wheat rice rotation through integrated use fertilizers, beneficial effect on yield and profitability.Pak.J.Soil Sci.23:23-27.

Alhaji, I.H. (2008). Yield performance of some cowpea varieties under sole and intercropping with maize at Bauchi, Nigeria.An Int. Multidis. J. 2:278-291.

Aluko (2014). Effects of inorganic and organic fertilizer on jute fluke. Vol.2,No.3,pp.1-9, September 2014

Ambasta, S.P., Chandran K.R., Kashyappa K. and Chand R. (1992).The Useful Plants of India.Publications and Information Directorate, CSIR, New Delhi.

Aspasia E, Bilalis D, Karkanis A, W illiams BF (2010). Combined organic and inorganic fertilization enhances soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. Australian Journal of Crop science,4(9): 722 -729.

Ayoola, O. T. and Makinde E. A. (2007). Fertilizer treatments effects on performance of cassava under two planting patterns in a cassava-based cropping system in south west Nigeria. Res.J.Agric. & Biol. Scis. 3(1):13-20.

Babajide P.A., Olabode O.S., Akanbi W.B., Olatunji O.O and Ewetola E.A. (2008). Influence of composted Tithonia-biomass and N-mineral fertilizer on soil physico-chemical properties and performance of tomato (*Lycopersicanlycopersicum*).Research Journal of Agronomy, 2(4): 101-106

Basso, B. and Ritchie, J.T. (2005). Impact of compost manure and inorganic fertilizer on nitrate leaching and yield for a 6 year maize alfalfa rotation in Michigan, Agriculture, Ecosystems and Environment, vol-108, pp. 309-341.

Black, C. A., Evans, D. D., White, J. L., Esminger, L. E. and Clark, F. E. (1965). Methods of Soil Analysis Part1: American Society of Agronomy, Madison, Wisconsin

Blaser B.C., Singer J.W. and Gibson L.R. (2007).Winter cereal, seeding rate and intercrop seeding rate effect on red clover yield and quality. Agron. J., 99: 723-729.

Brintha, I. and Seran T.H. (2009). Effect of paired row planting of radish (*Raphanussativus*L.) intercropped with vegetable amaranths (*Amaranths tricolor* L.) on yield components in sandy regosol. J. Agric. Sci. 4:19-28.

Catherine Tremblay andLéon Parent, (2002).Soil Acidity Determination Methods for Organic Soils and Peat Materials.

Chadha, M. L., & Mndiga, H. H. (2007). African eggplant—from underutilized to a commercially profitable venture. Acta Horticulturae, 752, 521–523.

Chang Ed-Haun, Wang Chong-Ho, Chen Chi-Ling and Chung Ren-Shih (2014). Effects of long-term treatments of different organic fertilizers complemented with chemical N fertilizer on the chemical and biological properties of soils, Soil Science and Plant Nutrition, 60:4, 499-511, DOI: 10.1080/00380768.2014.917333

Citak, S., Sonmez S. (2011) Effects of conventional and organic fertilization on spinach (Spinaceaoleracea L.) growth, yield, vitamin C and nitrate concentration during two successive seasons. ScientiaHorticulturae. 126:415-420

Chivenge, P.; Mabhaudhi, T.; Modi, A.T.; Mafongoya, P. (2015)The Potential Role of Neglected and Underutilised Crop Species as Future Crops under Water Scarce Conditions in Sub-Saharan Africa. Int. J. Environ. Res. Public Health, 12, 5685–5711.

Chivenge P, Vanlauwe B, Gentile R, Wangechi H, Mugendi D, van Kessel C, Six J (2009). Organic and mineral input management to enhance crop productivity in Central Kenya. Agron J 101:1266–1275

Cobo JG, Dercon G, Cadisch G (2010). Nutrient balances in African land use systems across different spatial scales: areview of approaches, challenges and progress. AgricEcosyst Environ 136:1–15

De Jager, A., Kariuku, I., Matiri, F. M., Odendo, M. and Wanyama, J. M. (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Linking nutrient balances andeconomic performances in three districts in Kenya. *Agr.Ecosys. Environ*. 71: 81-92.

Dou, X., He, P., Cheng, X., & Zhou, W. (2016). Long-term fertilization alters chemically-separated soil organic carbon pools: Based on stable C isotope analyses. *Scientific Reports*, *6*, 19061. http://doi.org/10.1038/srep19061

Edmonds, J.M and Chweya, J. A (1997). Black nightshades *Solanumnigrum*L. and related species, promoting the conservation and use of underutilized and neglected crops. 15 Institute of plant genetic and crop plant research. International Plants genetic resource institute Rome, Italy, 9-90.

Egbe, O.M., & Bar-Anyam,M.N. (2010). Pigeonpea/sorghum intercropping in Southern Guinea Savanna: effects of planting density of pigeonpea, *Nature and Science*,8(11), 156-167

El Sheikha AF (2016). Mixing Manure with Chemical Fertilizers, Why? and What is After? Nutr Food Technol 2(1): doi http://dx.doi. org/10.16966/2470-6086.112

Epstein, E. and Bloom, A. J. (2005). Mineral nutrition of plants: principles and perspectives. *2nd ednsunderland: Sinauer Associates; 2005.*Eyitayo A. Makinde (2013) Fertilizer Source on Growth and Cummulative Yield of Amaranthus,International Journal of Vegetable Science, DOI: 10.1080/19315260.2013.859203

Erasto P, Bojase–Moleta G and Majinda RRT (2004). Antimicrobial and antioxidant flavonoids from the roots wood of Bolusathusspesiosus. Phytochem.65, 875-880.

Fatima, Z., Aslam, M. and Bano, A. (2008) Chickpea nitrogen fixation increases production of subsequent wheat in a rain fed system. *Pak. J. Bot*., 40(1): 369-376.

FinkM.,FellerC.andScharpfH.C.(1999).Nitrogen,phosphorus,potassiumandmagnesiumcontentsoffiel dvegetables– Recent data for fertilizer recommendations and nutrient balances. Journal of Plant Nutrition and Soil Science, 162,71–73

Fustec, J., Lesuffleur F., Mahieu S. and Cliquet J.B. (2010). Nitrogen rhizodeposition of legumes: A review. Agron.Sust. Dev. 30:57-66.

Gachimbi, L. N., de Jager, A., van Keulen, H., Thuranira, E. G. and Nandwa, S. M. (2002). ParticipatoryDiagnosis of Soil Nutrient Depletion in Semi-Arid Areas of Kenya, Managing Africa's Soils No. 26.International Institute for Environment and Development, London, UK.

Gambo B. A., Magaji M.D., Yakubu A.I and Dikko A.U. (2008). Effects of Farmyard manure, nitrogen and weed interference on the growth and yield of onion (*Allium cepa*L.) at the Sokoto Rima valley. Journal of Sustainable development in Agriculture and Environment, 3(2): 87-92.

Geno, L., and B. Geno, (200). Polyculture Production: Principle, benefits and risk of multiple cropping. A report for the Rural Industry Research and Development Corporation (RIRDC), Publication, No. 01134.

Ghosh P. K., Mohanty M., Bandyopadhyay K. K., Painuli D. K. and Misra A. K. (2006). Growth, competition, yield advantage and economics in soybean/pigeonpea intercropping system in semi-arid tropics of India: I. Effect of subsoiling. Field CropRsch. 96:80-89

Gikonyo, P.C. Smithson, S.M. Nandwa, M. Lijzenga, B. Janssen**,** (2003).Effect of Potassium Fertilizer on some Major Food Crops in Kenya.

Giller KE (2002). Targeting management of organic resources and mineral fertilizers: can we match scientists' fantasies with farmers' realities? In: Vanlauwe B, Diels K, Sanginga N, Merckx R (eds) Integrared plant nutrient management in Sub-Saharan Africa: from concept to practice. CAB International, Wallingford, pp 155–171

Ginting D., Kessavalou A., Eghball B., Doran J.W. (2003). Greenhouse gas emissions and soil indicators four years after manure compost applications. J. Environ. Qual.32:23–32. doi: 10.2134/jeq2003.2300.

Gockowski, J., Mbaso, O.J., Mbah G and Moulende, T.F (2003).African traditional leafy vegetables and the urban and peri urban poor.Food policy. 28:221-235.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. (2010). Food security: the challenge of feeding nine billion people. *Science*, 327: 812–818.

Goulding, K., Jarvis, S., & Whitmore, A. (2008). Optimizing nutrient management for farm systems.*Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 667–680. http://doi.org/10.1098/rstb.2007.2177

Government of Kenya (2011). National Food and Nutrition Security Policy

Government of Kenya (2010).Kenya Vision 2030.

Gruhn P., Goletti F., Yudelman M. (2000). Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges, Food, Agriculture, and the Environment Discussion Paper 32. International Food Policy Research Institute, Washington, DC, USA.

Gurigbal, S. (2010). *The soybean: Botany, Production and Uses*. Ludhiana, India: Cabi Publishers.http://dx.doi.org/10.1079/9781845936440.0000

Hassan M.K., Chowdhury B.L.D. and Akhther N.(2010). Final Report- Postharvest Loss Assessment: A Study to Formulate Policy for Loss Reduction of Fruits and Vegetables and Socio-Economic Uplift of the Stakeholders, Department of Horticulture, Bangladesh Agricultural University, Mymensingh (Funded by USAID and EU & Jointly implemented by FAO and FPMU of MoFDM). p. 189

Hauggaard-Nielsen, Ambus H., P. and Jensen E.S. (2001). Temporal and spatial distribution of roots and competition for nitrogen in pea-barley intercrops - a field study employing 32P technique. Plant Soil 236:63-74.

Ijoyah, M. O., & Jimba, J. (2012). Evaluation of yield and yield components of maize (*Zea mays* L.)and okra(*Abelmoschus esculentus*) intercropping system at Makurdi, Nigeria. *J. Bio. Env. Sci., 2*(2), 38-44.

Indrani P. B., Arundhati B., and Jasbir S. (2008). Integrated use of legume green, manure and inorganic Fertilizer on soil health, nutrient uptake and Productivity of rice. Indian Journal of Agricultural Research 42 (4):260-265, Jorhat, Assam, India.

Jat, H. S. and Ahlawat, I. P. S. (2003). Response of pigeonpea+groundnut intercropping system to planting pattern and phosphorus management. *Indian J. Agron.*48: 156-59.

Jońca, Z and Lewandowski, W. (2004). Verification of Measurement Capabilities of Flame Atomic Spectrometry for the Determination of Sodium, Potassium, Magnesium, and Calcium in Natural Fresh Water Part I. Comparison of Recommended Methods, Polish Journal of Environmental Studies, Vol. 13, No. 3, pp. 275-280.

Kabura, B.H., Musa, B., Odo, P.E. (2008). Evaluation of the yield components and yield of onion (Allium cepa L.)–pepper (Capsicum annuum L.) intercrop in the Sudan savanna. J. Agron. 7:88–92.

Kamga, R.T., Kouamé, C., Atangana, A.R., Chagomoka, T., Ndango, R., (2013). Nutritional evaluation of five African indigenous vegetables. J. Hort. Res. 21, 99-106.

Kathuku, A.N., Kimani, S.K., Okalebo, J.R., Othieno, C.O. and Vanlauwe, B. (2007). 'The effects of integration of organic and inorganic sources of nutrient on maize yield in Central Kenya',inBationo, A., Maina, F.W., Wasswa, B., Kihara, J. and Okeyo, J. (Eds): *Innovations as Keyto the Green Revolution in Africa: Exploring the Scientific Facts,* African Network for Soil Biology and Fertility (AfNet), Nairobi, Kenya.

Kimani S.K., Mangale N., Gichuru M., Palm C., Njuho P. and Wamuongo J. (1998).Integrated Use and effects of Manure with Modest Application of Inorganic fertilizers on soil Properties and Maize production in the Central Kenya Highlands. Report no. 2 to Rockeffeler Foundation, December 1998.

Kipkosgei, L.K., Akundabweni L.S. and Hutchinson M.J., (2003).The effect of farmyard manure and nitrogen fertilizer on vegetative growth, leaf yield and quality attributes of *Solanumvillosum*(Black nightshade) in Keiyo district, rift valley. African Crop Science Conference Proceedings, 6: 514-518.

Kroeze, C., Aerts, R., Van Breemen, D., Van Dam, K. and Van der Hoek.(2003). Uncertainties in the fate of nitrogen I. An overview of sources of uncertainty illustrated with a Dutch case research. *NutrientCycling in Agro ecosystems.*66: 43-69.

Lambers H, Shane MW, Cramer MD, Pearse SJ, Veneklaas EJ. (2006). Root structure and functioning for efficient acquisition of phosphorus: matching morphological and physiological traits. Ann Bot (Lond)98: 693–713

Lesschen, Asiamah, Gicheru, Kanté, Stoovorgel, Smaling, (2003). Scaling Nutrient balances. Draft report, February 2003.

Li L, Zhang LZ, Zhang FS (2013). Crop Mixtures and the mechanisms of overyielding. In: Levin SA editors. Encyclopedia of biodiversity, second edition, Waltham, MA: Academic Press. Volume 2, pp. 382–395.

Lithourgidis, A.S., Dordas C.A., Damalas C.A. and Vlachostergios D.N. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. Aust. J. Crop Sci. 5:396-410.

Liu B., Liu XB., Wang C., Jin J., Harbert S.J. andHashemi M. (2010). Response of soybean yield and yield components to light enrichment and planting density.International Journal of Plant Production, 4 (1): 1-10.

Luis Miguel Brito, ÁureaSampaio, Rui Pinto, Isabel Mourão&JoãoCoutinho, (2016). Lettuce response to organic and phosphate fertilizers and root mycorrhization. Journal of Plant Nutrition 39:6, pages 842-849.

MaffiL. and WoodleyE. (2010). Biocultural Diversity Conservation – A Global Sourcebook Earthscan, London. 282p

Mahadeen A.Y and OudaB.A. (2008). Effect of fertilizers on growth, yield, yield components, quality and certain nutrient contents in broccoli (*Brassica oleracea*).International Journal of Agriculture and biology, 10(6): 627-632.

Makinde E.A. and Ayoola O.T. (2013). Residual Influence of early season crop fertilizationand cropping system on growth and yield of Cassava. American Journal of Agricultural andBiological Science 3: 712-715.

Makone, M. S., Basweti, A. E. and Ngeywo, C.J. (2015). Farmers' Response to Organic and Inorganic FertilizerUtilization on Maize Cropping Systems in Kisii County, Kenya. *IJPSS, 6(1): 26-33.*

Mao, L., Zang L., Li W., van der Werf W., Sun J., Spiertz H. and Li L. (2012). Yield advantage and water saving in maize/pea intercrop. Field Crops Res. 138:11-20.

Matusso J.M.M., Mugwe J.N., Mucheru-Muna M. (2014). Potential role of cereal-legume intercropping systems in integrated soil fertility management in smallholder farming systems of sub-Saharan Africa. Res. J. Agric. Environ. Manage. 3(3): 162-174.

Meena, S. Lal, Shamsudheen, M. and Devi Dayal (2008). Impact of row ratio and performance of clusterbean+sesame intercropping system.*Indian J. Agron.***53:** 285-89.

Miller A.J., Shen Q., Xu G.(2009). Freeways in the plant: transporters for N, P and S and their regulation. Current Opinion in Plant Biology; 12:284-290.

Mnzava N.A. and F.C. Ngwerume. (2004). *Cleome gynandra*. In: Grubben G.J.H. and Denton O.A.(Eds.). Plant Resources of Tropical Africa 2.Vegetables. PROTA Foundation, Wageningen,Netherlands,/Backhuys Publishers, leiden, Netherlands/CTA, Wageningen, Netherlands. P.191-195.

Mohamed F.M., Mohamed H.D., Mousa A.A and Emad-Elden F. (2007). Yield of Crops in Within-Row Intercropped Okra-Cowpea or Okra-Cucumber, International Journal of Vegetable Science,13:2, 33-48, DOI: 10.1300/J512v13n02_04

Morris M, Kelly VA, Kopicki RJ, Byerlee D (2007). Fertilizer use in African agriculture. Lessons learned and good practice guidelines. Directions in Development: Agriculture and Rural Development publication 39037 World Bank, Washington D C, 162 pp

Mtei, K. M., Ngome, A. F., Wambua, S. and Becker, M. (2013). Assessment of Technology Options Addressing Agricultural Production Constraints in Western Kenya. *Greener Journal of Agricultural Sciences*. Vol. 3 (3): 222-234. ISSN: 2276-7770

Mugendi, D., Mucheru-Muna, M., Mugwe, J. and Bationo, A. (2003). Enhancement of food productivity using leguminous shrubs in the Eastern highlands of Kenya.*African Crop Science ConferenceProceedings,* 6: 581-586.

Mutala, E.B. (2012). Efficacy of Organic N-Fertilizer on Maize Growth in a Vertisol and an Acrisol in the Accra Plains. Master of Philosophy in Soil Science Thesis, University Of Ghana, Legon.

Mugisha F, (2006). School enrollment among urban non-slum, slum and rural children in Kenya. 26:471–82.

Mwai G.N, and Schippers R.R. (2004). Solanum tarderemotum Bitter. In: Grubben GJH, Denton OA (Eds) Plant Resources of Tropical Africa 2. Vegetables, PROTA Foundation, Wageningen, Netherlands/ Backhuys Publishers, Leiden, Netherlands/ CTA, Wageningen, The Netherlands, pp 498-501

Mwangi S. and Kimathi M. (2006). African Leafy vegetables evolved from under-utilized special to commercial cash crops. In: research workshop on collective action and market access for smallholders. 2 - 5th October 2006. Cali, Colombia.

Narendhirakannan R.T., Kandaswamy M., Subramanian S. (2005). Anti-inflammatory activity of *Cleome gynandra* L. on hematological and cellular constituents in adjuvant-induced arthritis rats. J Med Food 8(1):93–99

Netondo G.W., Fuchaka W., Maina L., Naisiko T., Masayi N., Gaira J.K. (2010) Agro-biodiversity endangered by sugarcane farming in Mumias and Nzoia Sugar belts of Western Kenya. Afr.J. Environ. Sci. Technol. 4:437-445.

Ndakidemi P.A. and Dakora F.D. (2007). Yield components of nodulated cowpea (Vignaunguiculata (L.)Walp) and maize (Zea mays) plants grown with exogenous phosphorus in different cropping systems. Aust. J. Exp. Agric. **47:** 587-590.

Ndegwa A.M.M., Kimani A.W., Kirigua V., Kiuru P. D., Menza M.K., Muchui M.N. Omwenga J.Q., Wasike V.W., Wasilwa L., Waturu C.N. (2011). Report on Vegetable APVC Stakeholders Workshop, Held at KARI -Thika, 6th to 8th December 2010 pp. 23-29

Ndinya C. (2003). Seed production and supply system of three African leafy vegetables in Kakamega district. In M.O.Abukutsa*et al.* (Eds), Proceedings of Third Horticultural Workshop on Sustainable Horticultural Production in the Tropics. Department of Horticulture, Maseno University, Kenya, 60-67.

Nuruzzaman M, Lambers H, Bolland MDA, Veneklaas EJ (2005). Phosphorus uptake by grain legumes and subsequently grown wheat at different levels of residual phosphorus fertiliser. Aust J Agric Res 56:1041–1047 doi:10.1071/AR05060

Nyalala S. and B. Grout. (2007). African spider flower (*Cleome gynandra*L. /*Gynandropsisgynandra*(L.) Briq.)As a red spider mite (*Tetranychusurticae* Koch) repellent in cut-flower rose (*Rosa hybrid* L.) cultivation.*ScientiaHorticulturae*114: 194-198

Obuoyo J.A. (2005).The role of traditional crops inpromoting food security in the dry Siaya district,Kenya. MA thesis, MasenoUniversity,Kenya.

Ofori K. and Gamedoaghao D.K. (2005). Yield of scarlet eggplant (Solanumaethiopicum L.) as influenced by planting date of companion cowpea. ScientiaHorticalture105: 305-312.

Ojeniyi S.O, Oso O.P, Arotolu A.A. (2002). Response of vegetables to wood ash fertilizer.Proceeding of 35th annual conference of Agricultural Society ofNigeria. PP33-39

OjiewoC.O., Mwai G.N., Abukutsa-Onyango M.O., Agong S.G., Nono-womdimR., (2013). Exploiting the genetic diversity of vegetable African nightshades.Bioremidation, Biodiversity and Bioavailability 7, 6-13.

Okalebo, J. R., Gathna, K. W. and Woomer, P. L. (2002). Laboratory methods for soil and plant analysis.A working manual.Second Edition. Tropical soil fertility and Biology program, Nairobi Kenya. TSBFCIATand SACRED Africa, Nairobi Kenya. 128 pp.

Olufajo O.O. (1992). Response of soybean to intercropping with maize in a subhumid tropical environment.Trop. Oil seeds J. 1:27-33.

Oniang'o, R.K., Shiundu, M.K., Maundu, P., Johns, T. (2005). African Leafy Vegetables: Efforts to Change a Traditionally Subsistence Crop into a Major Driver in Poverty Alleviation and Improvement of Health in sub-Saharan Africa. International Consultation on the Value of Bio-diversity in Achieving the UN Millennium Development Goal of Freedom from Hunger and Poverty. Chennai, India.

Onim,M. and Mwaniki, P. (2008).Cataloguing and evaluation of available community/farmers-based seed enterprises on African indigenous vegetables (AIVs) in four ECA countries.pp 95.

Onwonga, R.N., Lelei, J.J., Freyer, B., Friedel, J.K., Mwonga, S.M., and Wandhawa P. (2008). Low Cost technologies for Enhancing N and P Availability and Maize (*Zea mays* L.) Performance on Acid Soils. World Journal of Agricultural Sciences 4 (S): 862-873.

Opala, P. A; Omami, E. N.; Opile, W. R.; Tuwei, C. (2013). "Response of the African nightshade to phosphate fertilizer application in Western Kenya". Scholars Research Library. *5 (1):195-201*

Payne, R.W., Harding, S.A., Murray, D.A., Soutar, D.M., Baird, D.B., Glaser, A.I., Welham, S.J., Gilmour, A.R., Thompson, R., and Webster, R. (2011). *GenStat Release 14 Reference Manual, Part 2 Directives*. VSN International, Hemel Hempstead, UK.

Park JH, Kalbitz K, Matzner E (2002). Resource control on the production of dissolved organic carbon and nitrogen in a deciduous forest floor. Soil BiolBiochem 34:813–822

Patterson, M.M., Cohen, E., Prommer, H., Thomas, D.G., Rhodes, S., McKinley, A.I.(2007). Origin of mixed brominated ethane groundwater plume: contaminant degradation pathways and reactions. Environmental Science & Technology 41: 1352-138.

Peter, J. S.,Y. L. Nancy, E. Roe, O. H. Monica and Donal, A. G. (1997). Utilization of composted organic wastes in vegetable production systems. University of Florida IFAS Indian river research and education center 21995. Rock road Ft. pierce FL 34945 U.S.A.Prasad, K.S. and N.K. Mohan. (1995) Intercropping of different vegetables and field species with brinjal. Ind. J. Agric. Sci. 65:39-41.

Phong, L. T., Stoorvogel, J. J., van Mensvoort, M. F., &Udo, H. M. J. (2011). Modeling the soil nutrient balance of integrated agriculture-aquaculture systems in the Mekong Delta, Vietnam.*Nutrient Cycling and Agroecosystems, 90*, 33–49.

Place F., Christopher B.B., Ade Freeman H., Ramisch J.J. and Vanlauwe B. (2003). Prospects for integrated soil fertility managementusing organic and inorganic inputs: evidence from smallholder African agricultural systems. Food Policy 28:365–378.

Powlsen D.S., MacDonald A.J., Poulton P.R. (2014). The continuing value of long-term field experiments: Insights for achieving food security and environmental integrity. In: Dent D (ed) Soil as world heritage. Springer, Dordrecht, pp 131–157. doi:10.1007/978-94-007-6187-2_16

Qasim, S.A., Anjum, M.A., Hussain, S. and Ahmad, S. (2013). Effect of pea intercropping on biological efficiencies and economics of some non-legume winter vegetables.*Pakistan Journal of Agricultural Sciences, 50*(3), pp.399-406.

Saker, P.K.,Rahman M.M. and Das B.C. (2007). Effect of intercropping of mustard with onion and garlic on aphid population and yield. J. Biol. Sci. 15:35-40.

Salami A,Kamara AB, Brixiova Z (2010). Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities, Working Papers Series N° 105 African Development

Santos H.S., Gliessman R. and Cecon R. (2002). Crop Interactions in Broccoli Intercropping, Biological Agriculture & Horticulture, 20:1, 51-75, DOI:10.1080/01448765.2002.9754948.

Schippers R.R.(2002). African indigenous vegetables and overview of the cultivated species. Chatham, UK. Natural Resources Institute /ACP-EU Technical Centre for Agricultural and rural Cooperation.Bank,Tunis, Tunisia.

Schnieders B.J. (1999). A quantitative analysis of inter-specific competition in crops with a row structure. PhD Thesis, Agricultural UniversityWageningen, The Netherlands

Segre, A. (1998). Global horticultural impact: Fruits and vegetables in developing countries.World conference on horticultural research, Rome, Italy.

Seran, T. H., & Brintha, I. (2010). Review on maize based intercropping. *Journal of Agronomy, 9*(3), 135-145.http://dx.doi.org/10.3923/ja.2010.135.145

Sharma RC, Banik PB (2012). Effect of integrated nutrient management on baby corn-rice cropping system: economic yield, system productivity, nutrient use efficiency and soil nutrient balance. Indian Journal of Agricultural Sciences, 82 (3): 220-224.

Shirani H., Hajabbasi M.A., Afyuni M., Hemmat A., (2002). Effects of farmyard manure and tillage systems on soil physical properties and corn yield in central Iran. – Soil and tillage research, 68(2):101–108.

ShiunduK.M., and Oniang'o R. (2007). Marketing African leafy vegetables, challenges and opportunities in the Kenyan context. African Journal of Food Agriculture Nutrition and Development 17: 4-12.

Sikora R.A. and Fernandez E.(2005). Nematode Parasites of Vegetables. In: Plant ParasiticNematodes in Subtropical and Tropical Agriculture. Luc M, Sikora RA, Bridge J (Editors) 2nd Edition, CABI Wallingford, UK. pp 319-392.

Singh, R.V. (1993). Production potential and economics of vegetables intercropped with rain fed okra. Ind. J. Hort. 50:73-76.

Smith, I.F.; Eyzaguirre, P. (2007)**.** African leafy vegetables: Their role in the World Health Organization's Global Fruit and Vegetable Initiative. African Journal of Food Agriculture Nutrition and Development 7**:** 1684-5374.

Soil fertility management handbook for extension staff and farmers in Kenya (2000)

Srinivasarao, Ch., Vittal, K.P.R., Kundu, S., Gajbhiye, P.N. and Vijayasankarbabu, M., (2010). Twenty years of continuouscropping, fertilization and organic manure application effects *Potassium mining in Indian agriculture*......... on forms of potassium and kinetics of non-exchangeable K release in the profile of an alfisol under arid conditions. Comm. Soil Sci. Plant Anal., 41 (6):783-796.

Steinmetz, K. A., & Potter, J. D. (1996). Vegetables, fruit, and cancer prevention: A review. *Journal of the American Dietetic Association, 96*, 1027–1039.

Sullivan, P., (2003). Intercropping principles and production practice. Agronomy Systems Guide. Appropriate Technology Transfer for Rural Areas (ATTRA). 1-12p.Available on: www.attra.necta.org

Suresh, K. D., Sneh, G., Krishn, K. K. and Mool, C. M. (2004). Microbial biomass carbon and microbial activities ofsoilsreceiving chemicalfertilizersAndorganicamendments.Archives Agronomy Soil Science50:7-641

Susan A.J., Mini C. (2005). Biological efficiency of intercropping in okra (*Abelmoschusesculentus*(L.) Moench). J Trop Agric; 43(1-2): 33-6.

Tenkouano, A. (2011). The nutritional and economic potential of vegetables. In World Watch Institute (Ed.), *The state of the world 2011: Innovations that nourish the planet* (pp. 27–35). Washington, DC: World Watch Institute

Thayamini, H. S., & Brintha, I. (2010). Review on Maize based intercropping. *Journal of Agronomy, 9*(3),135-145. http://dx.doi.org/10.3923/ja.2010.135.145

Thole, A. (2007). Adaptability of soybeans [Glycine max(L)merr] varieties to intercropping under leaf strippedand detasselled Maize (Zea mays L.). M. Sc thesis, Department of crop science, University of Zimbabwe.

Trdan S., Znidar D., Vali N., Rozman L. and Vidrih M. (2006). Intercropping against onion thrips, *Thripstabaci* Lindeman (Thysanoptera: Thripidae) in onion production: On the suitability of orchard grass, lacy phacelia and buckwheat as alternatives for white clover. J. Plant Dis. Protect., 113: 24-30.

Trdan S., Milevoj L.,ZeZlina I.,Raspudic E. and Andjus L. (2005). Feeding damage by onion thrips, *Thripstabaci* Lindeman (Thysanoptera: Thripidae), on early white cabbage grown under insecticide-free conditions. Afr. Entomol., 13: 85-95

Turner BL(2007). Inositol phosphates in soil: amounts, forms and significance of the phosphorylated inositol stereoisomers. In Tuner BL, Richardson AE, Mullaney EJ, eds, Inositol Phosphates; Linking Agriculture and the Environment. CABI, Wallingford, UK, pp 186–206

Van den Bosch H., Gitari J.N., Ogaro V.N., Maobe S. and Vlaming J. (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON). III.Monitoring nutrient flows and balances in three districts in Kenya. Agriculture ecosystems and environment 71 (1–3):63–80.

Vanlauwe B, Bationo A, Chianu J, Giller K, Merckx R, Mokwunye U, Ohiokpehai O, Pypers P, Tabo R, Shepherd K (2010a). Integrated soil fertility management operational definition and consequences for implementation and dissemination. OutlAgric 39:17–24

Veluri R, Weir TL, Bais HP, Stermitz FR, Vivanco JM.(2004). Phytotoxic and antimicrobial activities of catechin derivatives.J Agric Food Chem 52: 1077-1082.

Verma, R.K., A. Chauhan, R.S. Verma L. Rahman, and A. Bisht(2013). Improving production potential and resources use efficiency of peppermint (MenthapiperitaL.) intercropped with geranium. (Pelargonium graveolens L. Herit ex Ait) under different plant density. Crops Prod., 44, 577-582.

Verma S, Sharma PK (2007). Effect of long-term manuring and fertilizers on carbon pools, soil structure, and sustainability under different cropping systems in wet-temperate zone of northwest Himalayas. Biol Fertility Soils44: 235–240

Vlaming, J., Van Den Bosch, H., Van Wijk, M. S., de Jager, A., Bannink, A. and Van Keulen, H. (2001). Monitoring nutrient flows and economic performance in tropical farming systems

(NUTMON).Publishers: Alterra, Green World Research and Agricultural Economics Research Institute, LEI, The Netherlands.

Vos, J.,van der Putten, P.E.L. and Birch, C.J. (2005). Effect of nitrogen supply on leaf appearance, leaf growth, leaf nitrogen economy and photosynthesis capacity in maize (Zea mays L.). Field Crops Research 93: 64-73.

Wang, Z.H., Li, S., and Malhi, S. *(2008). Effects of fertilization and other agronomic measures on nutritional quality of crops.J. Sci. Food Agr. 88:7–23.*

Wanjekeche E., P. Powon, T. Mwangi, Z. Mac Osore and J. Wekesa.(2000). Effect of Inorganic Fertilizers and Farm Yard Manure on Mineral Composition and Taste of *Solanumnigrum*. In G Mureithi*et al.* (eds), The Proceedings of the 18th Conference and end of Millennium Celebrations, Mombasa, Kenya. Soil Science Society of East Africa, 2003; 208-393.

Warncke, D., Dahl, J. and Zandstra, B.(2004). Nutrient recommendations for Michigan vegetable crops. MSU Extension Bulletin Publication E2934. East Lansing, MI.

Watts D.B., Torbert H.A., Prior S.A., Huluka G. (2010). Long-term tillage and poultry litter impacts soil carbon and nitrogen mineralization and fertility. Soil Sci. Soc. Amer. J.74:1239–1247. doi: 10.2136/sssaj2008.0415.doi:10.1371/journal.pone.0062173

Wen-Jie, W., Ling, Q., Yuan-Gang, Z., Dong-Xue, S., Jing, A., Hong-Yan, W., Guan-Yu, Z., Wei, S. And Xi-Quan, C. (2011). Changes in soil organic carbon, nitrogen, pH and bulk density with the development of larch (*Larix gmelinii*) plantations in China. Global Change Biology, 17: 2657–2676. doi: 10.1111/j.1365-2486.2011.02447.x

Xiao X., Cheng Z., Meng H., Liu L., Li H., Dong Y. (2013). Intercropping of green garlic (*Allium sativum* L.) induces nutrient concentration changes in the soil and plants in continuously cropped cucumber (*Cucumis sativus* L.) in a plastic tunnel. *PLoS ONE* 8:e62173 10.1371/journal.pone.0062173

Yang Z, Xu M, Zheng S, Nie J, Gao J, Liao Y, Xie J (2012). Effects of long-term winter planted green manure on physical properties of reddish paddy soil under a double-rice cropping system. J. Integr. Agric., 11, 655–664. doi:10.1016/S2095-3119(12)60053-7

Yang R.Y. and Keding G.B. (2009). Nutritional contributions of important African indigenous vegetables: African indigenous vegetables in urban agricul-ture.(Shackleton C.M., Pasquini M.W., Drescher A.W., eds.)London, Earth scan, pp.:105-143.

Zhang FS,and Li L. (2003). Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. Structure and functioning of cluster roots and plant responses to phosphate deficiency. Springer: 305–312.

Zhang, J. W., Chang-Hao, H. U., Kong-Jun, W. A. N. G., Shu-Ting, D. O. N. G., & Peng, L. I. U. (2004). Effects of plant density on forage nutritive value of whole plant corn. *Agricultural Sci. in China, 3*(11), 842-848.

Zhao, Y., Wang, P., Li, J., Chen, Y., Ying, X. and Liu, S. (2009).The effect of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat-maize cropping system. Eur. J. Agron., 31: 36-42.

Zhao, D., Reddy, K.R., Kakani, V.G. and Reddy, V.R.(2005). Nitrogen deficiency effects on plant growth, leaf photosynthesis, and hyperspectral reflectance properties of sorghum. *European J. Agron*. 22, 391–403.